SOLAR PHYSICS COMMITTEE.

I.—COMPARISON OF THE SPECTRA OF RIGELIAN, CRUCIAN AND ALNITAMIAN STARS.

II.—A DISCUSSION OF THE LINE SPECTRUM OF α ORIONIS.

III.—THE SPECTRUM OF γ CASSIOPEIÆ.

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AND

ITS RELATION TO THAT OF ARCTURUS AND THE FRAUNHOFERIC SPECTRUM.

III.—THE SPECTRUM OF γ CASSIOPEIÆ.

BY

FRANK E. BAXANDALL, A.R.C.S.,
First Assistant, Solar Physics Observatory.

UNDER THE DIRECTION OF
SIR NORMAN LOCKYER, K.C.B., LL.D., Sc.D., F.R.S.

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Report by the Committee on Solar Physics	(1882)
Second Report by the Committee on Solar Physics	(1889)
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Researches on the Chemical Origin of Various lines in Solar and Stellar Spectra ...	(1910)
Positions and Areas of Sun-Spots and Faculæ, 1907 and 1908	(1911)
,, ,, ,, ,, 1909	(1911)
,, ,, ,, ,, 1910	(1911)
Report of the Solar Eclipse Expedition to Vavau, Tonga Islands, April 29, 1911 (Eastern date)	(1912)
(I.) On the Spectra of Rigelian . . . Stars; (II.) The Line Spectrum of α Orionis; (III.) The Spectrum of γ Cassiopeiæ (one volume)	(1914)
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II.—Photographic Comparison of the Spectra of the typical Stars of the Rigelian, Crucian, and Alnitamian Groups (enlarged 3·5 times).

III.—Diagram showing the Chief "Unknown" Lines in the Spectra of the Rigelian, Crucian, and Alnitamian Stars.

PREFACE.

The three papers now published are a continuation of memoirs dealing with the classification of stars based on their chemistry, as exhibited in their spectra. In "A Catalogue of 470 of the Brighter Stars Classified according to their Chemistry"* I arranged the objects therein dealt with in accordance with the appearance of the lines of the several elements at different temperature—ascending or descending—levels. In that work it was indicated that a much more extensive spectroscopic catalogue would become necessary, and in subsequent papers† it has been pointed out that as the work proceeded a subdivision of the main genera first proposed was shown to be necessary.

In the present paper on the "Comparison of the Spectra of Rigelian, Crucian, and Alnitamian Stars," such a subdivision is made of the "Alnitamian" genus, and the relations of the various species to those in the neighbouring genera are discussed more fully than they were in the earlier paper on "The Sequence of Chemical Forms in Stellar Spectra."‡

It will be seen that the subdivision in no way upsets, or runs counter to, the main division. In fact the latter is strengthened by the strict uniformity in the chemical steps of the subdivision. It is interesting to note that there now remain but very few prominent lines in the spectra of the Orion Stars here considered which have not been definitely traced to their terrestrial origin.

In the second paper the spectrum of α Orionis, a star low-down on the ascending branch of the temperature curve is considered in detail and compared with that of Arcturus, a star of nearly equal temperature on the descending side, and the Fraunhoferic Spectrum. As I have previously pointed out,§ Arcturus is shown, by the elements predominantly represented in its spectrum, to be on a lower "temperature" level than the sun, and we now find it a convenient step between the Antarian (the lowest) horizon and the level represented by the solar type of spectrum.

In the paper above referred to it was shown that in the chemistry of these lower levels the elements vanadium and titanium play a most important part, the variations of intensity of the lines in their spectra being one of the principal indices of change. So important was this feature that special attention was paid to it in a memoir on "The Spectroscopic Comparison of Metals Present in "Certain Terrestrial and Celestial Light-Sources (with special reference to "Vanadium and Titanium)" published‖ from this Observatory in 1907. In that paper many solar lines previously described as of unknown origin were shown to be due to vanadium and titanium, and it was also shown that the

* Solar Physics Committee Publication. 1902.

† Roy. Soc. Proc. Vol. 65, p. 191, Vol. 74, p. 53, Vol. 76, p. 150, &c., Vol. 84, p. 430, &c.

‡ Roy. Soc. Proc. Vol. 84, pp. 426–432. § Roy. Soc. Proc. Vol. 74, p. 54.

‖ Solar Physics Committee Publication. 1907.

same elements are of special significance in the spectra of sun-spots. The subject is now developed further, thus not only throwing more light on the relationships between the spectroscopic phenomena of the sun and those of the stars of the neighbouring genera, but indicating that α Orionis on one arm of the temperature curve is of lower temperature than Arcturus on the other.

The photographs involved in the inquiry have been taken by various members of the staff. They have been reduced, compared, and discussed by Mr. Baxandall, who has also written the papers.

NORMAN LOCKYER.

Solar Physics Observatory
March 11, 1913.

PART I.

COMPARISON OF THE SPECTRA OF RIGELIAN, CRUCIAN, AND ALNITAMIAN STARS.

INTRODUCTION.

The wave-lengths, intensities, and probable origin of lines in the type stars of the Rigelian, Crucian, and Alnitamian groups have already been recorded in a Kensington publication.* Since the date of that paper, however, much new light has been obtained on the identity of lines in these spectra with lines belonging to terrestrial spectra, and consequently on the wave-lengths of the stellar lines.

The stars previously investigated were β Orionis, γ Orionis, and ϵ Orionis, which are respectively the type stars of the Rigelian, Crucian, and Alnitamian groups. It has been found that amongst stars included in the Alnitamian group there are such spectrum differences as to warrant a subdivision of that group. In this connection the spectra of ϵ, κ, ζ, and ι Orionis—all Alnitamian stars—have been investigated, and the deduced wave-lengths, intensities, and probable origins of the lines inter-compared. The present paper consists of a comparison of the spectra of β Orionis (Rigelian), γ Orionis (Crucian)—which have been obtained with higher dispersion (two 6-inch Henry prisms) than that used in connection with the previous record—and the spectra of the four Alnitamian stars mentioned above, the latter having been obtained with one 6-inch Henry prism.

The following table shows the wave-lengths and intensities of the lines occurring in these individual spectra, so that the relative intensities of the lines common to several of the spectra can be seen at a glance. From the investigation of the relative intensities in these stars of lines typical of various terrestrial elements, it has been found that in going up the stellar temperature scale from the Rigelian (β Orionis) stage, through the Crucian (γ Orionis), and Alnitamian (ϵ Orionis), the four Alnitamian stars involved must be placed in the following order—κ, ϵ, ζ, and ι Orionis—the first of these approaching most closely in spectrum type to that of the group below (Crucian), and ι Orionis to the group above (Argonian).

In the main the identity of the stellar lines with lines in terrestrial spectra has been established by an actual matching of the lines in the two sets of spectra photographed to the same scale.

* Catalogue of 470 of the Brighter Stars. (Published by the Solar Physics Committee 1902.)

TABULAR COMPARISON OF THE LINES IN THE SPECTRA OF RIGELIAN, CRUCIAN, AND ALNITAMIAN STARS.

(β, γ, κ, ϵ, ζ, and ι Orionis.)

λ.	Probable Origin.	λ of Probable Origin.	Intensity.						Remarks.
			β Orionis.	γ Orionis.	κ Orionis.	ϵ Orionis.	ζ Orionis.	ι Orionis.	
3798·0	H	3798·0	—	—	—	6	6	—	
3819·8	He	3819·75	—	—	—	7	5	—	
3835·6	H	3835·6	—	—	—	8	7	6	
3853·8	Si (II.)	3853·82	2	—	—	—	—	—	
3856·2	Si (II.)	3856·19	4	—	—	—	—	—	
3862·8	Si (II.)	3862·80	5	—	—	—	—	—	
3867·6	He	3867·61	2	—	—	—	—	—	
3872·0	Ast	3871·95	3	—	—	—	—	—	
3889·0	He	3888·79	10	10	10	10	10	8	Hζ.
	H	3889·15							
3912·2	O	3912·20	—	2	—	—	—	—	
3913·4	—	—	—	—	1	1–2	2	—	
3919·2	N	3919·24	2	3	2	1–2	—	—	
3920·8	p. C	3920·80	3	2	2	1	—	—	
3923·6	—	—	1	—	—	—	—	—	
3924·3	—	—	—	1–2	—	—	—	—	
3926·7	Ast	3926·68	3	5	3	1–2	< 1	< 1	
3932·4	—	—	1	—	—	—	—	—	
3933·8	p. Ca	3933·83	9	3–4	3–4	3–4	2–3	1	
3936·1	Ast	3936·06	1–2	1–2	1	1	—	—	
3939·3	—	—	1	—	—	—	—	—	
3940·2	N	3940·20	—	< 1	—	—	—	—	
3945·3	O	3945·25	—	1–2	2–3	1–2	—	—	
3947·5	O	3947·55	—	1	—	—	—	—	
3954·6	O	3954·55	—	1–2	2	2	1–2	—	
3956·0	N	3956·04	—	1	1	—	—	—	
3961·8	—	—	—	1–2	1–2	2–3	—	—	
3964·9	Ast	3964·88	5	5–6	4	3–4	1	1	
3966·7	—	—	—	1	—	—	—	—	
3968·6	p. Ca	3968·63	10	3–4	3	3	3	—	
3970·2	H	3970·25	10	10	10	10	10	9	Hε.
3972·6	—	—	1	—	—	—	—	—	
3973·4	O	3973·44	—	2	2	1–2	—	—	
3980·5	—	—	—	1	—	—	—	—	
3982·9	O	3982·90	—	1–2	1	1	—	—	
3991·1	—	—	—	1	—	—	—	—	
3993·1	—	—	—	1	—	—	—	—	
3995·2	N	3995·26	2	4	2–3	1–2	1	1	
3997·1	—	—	—	—	—	< 1	—	—	
3999·0	—	—	—	1	—	—	—	—	
4003·0	—	—	—	—	—	1	—	—	
4005·0	—	—	—	1–2	—	—	—	—	
*4009·4	Ast	4009·42	4–5	7	5–6	4	2–3	2	
4012·5	—	—	< 1	1	< 1	< 1	—	—	
4015·0	—	—	—	1	—	—	—	—	
4015·8	p. Ni	4015·76	< 1	—	—	—	—	—	
4018·5	—	—	—	—	—	—	1–2	—	
4021·0	—	—	—	—	—	1–2	—	—	
4024·1	Ast	4024·13	—	1	—	—	—	—	
4026·3	He	4026·34	6–7	9	8–9	8	7–8	7	In ε, ζ, and ι Orionis probably partly due to proto-hydrogen.
4028·5	p. Ti	—	1	—	—	—	—	—	
4031·1	—	—	—	1	—	—	—	—	
4033·2	—	—	1	—	—	—	—	—	

λ.	Probable Origin.	λ of Probable Origin.	Intensity, β Orionis.	γ Orionis.	κ Orionis.	ε Orionis.	ζ Orionis.	ι Orionis.	Remarks.
4035·1	N	4035·07	—	2–3	2	1	< 1	—	
4039·0	—	—	—	1–2	—	—	—	—	
4041·5	N	4041·48	—	2–3	2	1	< 1	—	
4043·8	—	—	—	1–2	—	—	—	—	
4048·5	—	—	—	1	—	—	—	—	
4050·5	—	—	—	1	—	—	—	—	
4057·5	—	—	—	1	—	—	—	—	
4061·6	—	—	—	1	—	—	—	—	
4065·0	—	—	—	—	—	1	—	—	
4067·3	p. Ni	4067·30	1–2	—	—	—	—	—	
4067·8	—	—	—	1	—	—	—	—	
4069·7	—	—	—	—	3–4	4	4–5	2	Probably compound line involving strange line and O 4070·1.
4070·0	O	4070·04	< 1	3	—	—	—	—	
4072·4	O	4072·40	< 1	3	2	2	1	1–2	
4076·1	O	4076·08	< 1	3	4	4	2	2	
4079·1	O	4079·11	—	1	1	1	—	—	
4085·4	O	4085·36	—	1–2	1	1	—	—	
4089·1	Si (IV.)	4089·09	—	2	8	9	7–8	5	
4093·2	O	4093·15	—	1	2	1–2	1–2	—	
4097·4	N	4097·43	—	2	5	6	4	3–4	Nitrogen line of abnormal behaviour (*see* Roy. Soc. Proc., Vol. 82, p. 534.)
4101·8	H	4101·85	10	10	10	10	10	10	Hδ.
4105·2	O	4105·15	—	1	—	—	—	—	
4111·1	O	4111·06	—	< 1	—	—	—	—	
4111·4	—	—	—	—	—	—	1–2	—	
4112·3	O	4112·26	—	< 1	—	—	—	—	
4116·5	Si (IV.)	4116·51	—	1	6	8	5–6	3	
4119·5	O	4119·46	—	1–2	—	—	—	—	
4121·0	He	4120·97	3–4	5–6	5	4	3	3	
4124·3	O	4124·27	—	1	—	—	—	—	
4125·0	—	—	—	—	—	—	1	—	
4128·2	Si (II.)	4128·20	6	1	< 1	< 1	< 1	< 1	
4129·8	—	—	1	—	—	—	—	—	
4131·0	Si (II.)	4131·04	6	1	< 1	< 1	< 1	< 1	
4134·0	? N	4133·85	—	1	1	1	1	—	
4139·0	—	—	—	1	1	1	—	—	
4142·8	S	4143·00	1	—	—	—	—	—	
4143·9	Ast	4143·92	4–5	8	5–6	5	3–4	3	
4145·5	S	4145·75	1	—	—	—	—	—	
4146·0	N	4146·03	—	< 1	1	1	—	—	
4149·7	—	—	—	—	—	1	—	—	
4150·0	—	—	—	2	—	—	—	—	
4153·7	S O	4153·56 4153·85	1–2	2–3	2	2	1	—	Probably due to sulphur in β Orionis and to oxygen in other stars.
4155·0	—	—	—	—	—	—	—	1	
4156·7	? O	4156·83	—	1	1–2	—	—	—	
4163·0	S	4163·30	2–3	1	—	—	—	—	
4165·0	—	—	—	1–2	—	—	—	—	
4169·1	Ast	4169·13	2	3–4	1–2	1–2	1	1	
4171·3	—	—	—	1	—		—	—	
4174·0	p. Fe S	4173·61 4174·47	2	—	—	—	—	—	
4176·2	N	4176·16	—	1	—	—	—	—	
4179·0	p. Fe	4179·03	2	1	—	—	—	—	
4185·7	O	4185·72	—	2	2	2–3	2–3	1	
4190·1	O	4190·06	—	2	2	1–2	1–2	1	
4196·2	? N	4196·20	—	1	1	1	—	—	

λ.	Probable Origin.	λ of Probable Origin.	Intensity.						Remarks.
			β Orionis.	γ Orionis.	κ Orionis.	ε Orionis	ζ Orionis.	ι Orionis.	
4200·5	p. II	*	—	—	1	2	3–4	4	* Recently traced in laboratory spectra by Prof. Fowler (*Monthly Notices*, R.A.S., vol 73, No. 2, December 1912).
4220·0	—	—	—	—	—	—	2	—	This line seems quite special to ζ Orionis. It is near but apparently not exactly coincident with the strongest line of phosphorus.
4223·4	N	4223·35	—	1	—	—	—	—	
4228·6	N	4228·56	—	1	—	—	—	—	
4233·3	p. Fe	4233·33	3–4	1	—	—	—	—	
4236·9	N	4236·93	—	2	1	1	—	—	
4241·9	N	4241·94	—	2–3	1	1	—	—	
4242·5	p. Cr	4242·54	1	—	—	—	—	—	
4247·3	—	—	—	—	—	1	—	—	
4253·8	S	4253·77	—	2–3	4	3	1–2	1	Abnormal line of sulphur (*see* Roy. Soc. Proc., Vol. 80, pp. 51 and 55).
4258·4	—	—	< 1	—	—	—	—	—	
4262·1	p. Cr	4262·15	< 1	—	—	—	—	—	
4264·2	—	—	1	1	1	1	—	—	
4265·6	—	—	< 1	—	—	—	—	—	
4267·3	p. C	4267·30	4–5	5–6	3–4	3–4	1–2	1	
4269·6	—	—	< 1	—	—	—	—	—	
4272·4	—	—	—	1	—	—	—	—	
4276·2	—	—	—	2	2–3	1–2	1	1	
4285·1	S	4285·13	—	1–2	2–3	1–2	1	< 1	Abnormal line of sulphur (*see* Roy. Soc. Proc., Vol. 80, pp. 51 and 55).
4290·4	p. Ti	4290·38	< 1	—	—	—	—	—	
4292·2	—	—	< 1	1	—	—	—	—	
4294·2	p. Ti	4294·20	1–2	—	—	—	—	—	
4295·0	—	4295·0	—	1	—	—	—	—	
4296·7	p. Fe	4296·72	< 1	—	—	—	—	—	
4303·3	p. Fe	4303·34	2	—	—	—	—	—	
4304·2	—	—	—	1	1–2	1–2	1–2	—	
4308·1	p. Ti	4308·10	< 1	—	—	—	—	—	
4313·0	p. Ti	4313·03	< 1	—	—	—	—	—	
4315·1	p. Ti	4315·14	< 1	—	—	—	—	—	
4317·3	O	4317·27	—	1–2	2	2	1–2	1	
4319·8	O	4319·78	—	1–2	3	2	1–2	1	
4325·9	O	4325·85	< 1	1	1–2	1–2	< 1	< 1	Probably due to something other than O in β Orionis. Probably remaining trace of the stronger line of α Cygni.
4327·6	O	4327·61	—	1–2	1	1	—	—	
4331·2	O	4331·23	—	1	—	—	—	—	
4332·9	? N	4332·62	—	—	1–2	1–2	—	—	
4334·0	—	—	—	1	—	—	—	—	
4337·0	O	4337·01	—	1	—	—	—	—	
4338·1	p. Ti	4338·08	1	—	—	—	—	—	
4340·7	H	4340·66	10	10	10	10	10	10	
4343·2	—	—	—	1	—	—	—	—	
4345·7	O	4345·71	—	1	1	3	—	—	
4347·6	O	4347·58	—	< 1	1	1	—	—	
4349·6	O	4349·57	—	1-2	3–4	3–4	1–2	—	
4351·5	O	4351·54	—	1-2	1–2	2	1	1	
4351·9	p. Fe	4351·93	2	—	—	—	—	—	
4354·0	—	—	—	—	—	1	—	—	
4361·5	—	—	—	1	1	1	—	—	
4367·0	O	4367·04	—	2	2–3	3	1–2	—	
4370·5	—	—	—	—	1	—	—	—	

λ.	Probable Origin.	λ of Probable Origin.	Intensity.						Remarks.
			β Orionis.	γ Orionis.	ε Orionis.	ε Orionis.	ζ Orionis.	ι Orionis.	
4372·2	—	—	—	1–2	—	1	—	—	
4374·0	—	—	—	—	1	—	—	—	
4379·8	N	4379·75	—	1	2	3	1–2	—	Nitrogen line of abnormal behaviour (*see* Roy. Soc. Proc., Vol. 82, p. 540.)
4384·0	—	—	—	—	—	1	—	—	
4385·5	p. Fe	4385·55	1	—	—	—	—	—	
4388·1	Ast	4388·10	4	8	7	6–7	5	2-3	
4391·2	p. Ti	4391·19	1	—	—	—	—	—	
4395·2	p. Ti	4395·20	1	—	—	—	—	—	
4396·1	O	4396·14	—	2–3	—	—	—	—	
4399·9	p. Ti	4399·94	< 1	—	—	—	—	—	
4412·0	—	—	—	1	—	—	—	—	
4415·1	O	4415·07	—	2–3	3	2	2	1	
4417·0	p. Fe O	4416·99 4417·14	1–2	2	2–3	2	1–2	1	Probably due chiefly to p. Fe in β Orionis, but wholly or chiefly due to O in other stars.
4419·6	—	—	—	1–2	—	—	—	—	
4422·1	—	—	—	1	—	—	—	—	
4426·1	N	4426·10	—	1	—	—	—	—	
4432·9	N	4432·9	—	1–2	1	1	—	—	
4437·7	Ast	4437·72	2	3	1–2	1	—	—	
4442·5	—	—	—	1	—	—	—	—	
4444·0	p. Ti	4443·98	1	—	—	—	—	—	
4447·2	N	4447·23	—	3	1–2	1	—	—	
4452·6	O	4452·57	—	1	—	—	—	—	
4453·5	—	—	—	—	1–2	1	—	—	
4460·3	N	4460·25	—	1	—	—	—	—	
4462·0	—	—	—	—	—	—	1	—	
4464·1	—	—	—	1	—	—	—	—	
4464·6	S	4464·90	1	—	—	—	—	—	
4465·5	O	4465·54	—	1	1	1–2	—	—	
4468·7	p. Ti	4468·66	< 1	—	—	—	—	—	
4471·6	He	4471·65	6–7	8	7–8	7–8	7–8	7	
4477·5	—	—	—	1	1	1	—	—	
4481·4	p. Mg	4481·40	7–8	4–5	3	3	2	2	
4487·6	—	—	—	1	—	—	—	—	
4489·4	p. Fe	4489·35	< 1	—	—	—	—	—	
4491·0	—	—	—	1	1	1	—	—	
4491·6	p. Fe	4491·57	< 1	—	—	—	—	—	
4492·5	—	—	—	—	—	—	1	—	
4501·5	p. Ti	4501·45	< 1	—	—	—	—	—	
4507·7	N	4507·78	—	1	1	1–2	—	—	
4508·5	p. Fe	4508·46	1–2	—	—	—	—	—	
4511·0	—	—	—	—	—	1	—	—	
4513·5	—	—	—	1–2	1–2	1–2	—	—	
4514.3	—	—	—	—	—	—	—	1	
4515·5	p. Fe	4515·51	1	—	—	—	—	—	
4518·6	—	—	—	1	—	—	—	—	
4520·4	p. Fe	4520·40	1	—	—	—	—	—	
4522·8	p. Fe	4522·77	2	—	—	—	—	—	
4524·5	—	—	—	1	—	—	—	—	
4525·3	S	4525·16	1	—	—	—	—	—	
4529·6	—	—	—	—	—	—	—	< 1	
4530·1	N	4530·08	—	3	1	1	—	—	
4534·1	—	—	1	—	—	—	—	—	
4541·4	p. Fe	4541·46	1	—	—	—	—	—	
4542·4	p. H	*	—	—	1	1–2	4	4	* Recently traced in laboratory spectra by Prof. Fowler (*Monthly Notices*, R.A.S., Vol. 73., No. 2, December 1912).

λ.	Probable Origin.	λ of Probable Origin.	Intensity.						Remarks.
			β Orionis.	γ Orionis.	κ Orionis.	ε Orionis.	ζ Orionis.	ι Orionis.	
4549·6	p. Fe p. Ti	4549·64 4549·81	3	< 1	—	—	—	—	
4552·7	N Si (III.)	4552·65 4552·64	2	4–5	5–6	5	2	1–2	This stellar line is probably, in the main, due to Silicium 4552·64.
4556·1	p. Fe	4556·09	1–2	—	—	—	—	—	
4558·8	p. Cr	4558·83	1	—	—	—	—	—	
4559·5	—	—	—	—	2	—	—	—	
4562·0	—	—	1	—	—	—	—	—	
4563·9	p. Ti	4563·94	< 1	—	—	—	—	—	
4565·0	—	—	—	1	—	—	—	—	
4567·9	Si (III.)	4567·90	1–2	4	4	4	1–2	1	
4571·4	—	—	—	1–2	—	—	—	—	
4572·2	—	—	< 1	—	—	—	—	—	
4574·8	Si (III.)	4574·79	1	3	2–3	2–3	1	< 1	
4584·0	p. Fe	4584·02	3–4	1	—	—	—	—	
4588·3	p. Cr	4588·38	1	—	—	—	—	—	
4591·1	O	4591·13	—	2–3	2–3	1–2	—	1	
4592·3	p. Cr	4592·25	< 1	—	—	—	—	—	
4596·3	O	4596·31	—	2–3	2	2	—	1	
4601·7	N	4601·67	—	2	< 1	< 1	—	—	
4607·3	N	4607·34	—	2	1	< 1	—	—	
4609·7	—	—	—	1	1	2	—	—	
4614·0	N	4614·05	—	2	< 1	< 1	—	—	
4619·0	p. Cr	4618·97	1	—	—	—	—	—	
4621·6	N	4621·57	—	2	1	< 1	—	—	
4629·5	p. Fe	4629·60	1	—	—	—	—	—	
4630·7	N	4630·73	2	3–4	3	2–3	1–2	1–2	
4635·5	—	—	1–2	—	—	—	—	—	
4639·0	O	4638·99	—	2	1–2	1	1	—	
4641·9	O	4641·94	—	2–3	4	3–4	2	—	
4643·3	N	4643·27	—	2	< 1	< 1	—	—	
4645·0	—	—	—	—	—	1	—	—	
4647·6	p. C	4647·53	—	?	7	8	6–7	4	*See* Roy. Soc. Proc., Vol. 82, p. 541.
4649·2	O	4649·26	—	3	—	—	—	—	
4650·8	p. C	4650·92	—	?	7	8	6–7	4	*See* Roy. Soc. Proc., Vol. 82, p. 541.
4654·6	—	—	—	—	—	3	—	—	Apparently coincident with weak N. line, but intensity too high for N. only in star. This line seems quite special to ε Orionis.
4657·4	p. Ti	4657·38	1	—	—	—	—	—	
4661·8	O	4661·76	—	2–3	3–4	3	1–2	—	
4662·8	—	—	1	—	—	—	—	—	
1666·0	—	—	—	—	—	1	—	—	
4670·9	—	—	—	1	—	—	—	—	
4676·3	O	4676·34	—	1–2	3	3	2	—	
4682·0	—	—	—	—	—	1–2	—	—	
4685·9	p. H	*4685·97	—	—	2–3	4	4	6	*See Roy. Soc. Proc., Vol. 74, p. 546.
4699·4	O	4699·39	—	1–2	1–2	1	—	—	
4705·6	O	4705·56	—	1–2	1–2	1	—	—	
4710·3	O	4710·3	—	1	—	—	—	—	
4713·3	He	4713·25	4	6	6	6	4	4	
4715·9	S	4715·9	1–2	1	—	—	—	—	
4815·7	S	4815·3	3	1	—	—	—	—	
4824·3	p. Cr	4824·33	< 1	—	—	—	—	—	
4848·4	p. Cr	4848·44	< 1	—	—	—	—	—	

λ.	Probable Origin.	λ of Probable Origin.	Intensity.						Remarks.
			β Orionis.	γ Orionis.	κ Orionis.	ε Orionis.	ζ Orionis.	ι Orionis.	
4861·5	H	4861·49	10	10	10	10	10	10	
4917·6	S	4917·4	1	—	—	—	—	—	
4922·1	Ast	4922·10	6	8	—	—	—	—	
4924·1	p. Fe	4924·11	4	—	—	—	—	—	
4925·7	S	4925·5	1	—	—	—	—	—	
4992·5	S	4992·15	1	—	—	—	—	—	
5003·0	N	5002·7	2	—	—	—	—	—	
5006·0	N	5005·7	1–2	—	—	—	—	—	
5010·0	S	5010·0	1	—	—	—	—	—	
5014·4	S	5014·2	1	—	—	—	—	—	
5015·7	Ast	5015·73	4	6	—	—	—	—	
5018·6	p. Fe	5018·63	5	—	—	—	—	—	
5027·8	S	5027·9	2	—	—	—	—	—	
5032·9	S	5033·0	3	—	—	—	—	—	
5042·0	Si (II.)	5042·0	3	—	—	—	—	—	
5047·8	Ast	5047·82	2–3	—	—	—	—	—	
5057·0	Si (II.)	5057·0	5	—	—	—	—	—	

NOTES ON TYPICAL LINES OF THE VARIOUS CHEMICAL FORMS.

In the following notes Alnitamian I. = κ Orionis, Alnitamian II. = ε Orionis, Alnitamian III. = ζ Orionis, Alnitamian IV. = ι Orionis.

A chart has been prepared showing the relative intensities through the sequence of stellar spectra, of well-known lines representative of various terrestrial elements. It will be instructive to give a short account of these sequential intensity-changes in the various lines in passing from the lowest stage dealt with (Rigelian) to the highest (Argonian).

HYDROGEN.

(Representative line H γ 4340·66.)

With regard to hydrogen lines, it may be said at once that these are predominant in *all* the spectra discussed, and show little change in intensity from the bottom level to the top. Throughout the Crucian and Alnitamian groups there is little or no difference in the intensity of the hydrogen lines, but at the lower Rigelian stage and the higher Argonian stage the hydrogen lines are somewhat less prominent.

PROTO-CALCIUM.

(Representative line K 3933·83.)

This is quite a conspicuous line at the Rigelian stage. It is much weaker and fairly uniform in intensity through the Crucian, Alnitamian (I.), and Alnitamian (II.) stages, and weakens still further through the Alnitamian (III. and IV.) stages, being quite an inconspicuous line at the top level mentioned.

PROTO-MAGNESIUM.

(Representative line 4481·40.)

This is also quite conspicuous at the Rigelian stage, weakens considerably at the Crucian stage, and gradually further weakens at the successive Alnitamian levels.

SILICIUM (II.).

(Representative line 4128·20.)

This line is well marked at the Rigelian level; its intensity has much decreased at the Crucian and Alnitamian (I.) stage and has weakened almost to evanescence at the high Alnitamian levels II., III., and IV.

PROTO-IRON.

(Representative line 4233·33.)

This line occurs at the two lower stages, Rigelian, where it is a line of only moderate intensity, and Crucian, where it is very weak. It does not exist in the Alnitamian stars.

SULPHUR (Ordinary Spark Lines).

(Representative line 4815·3.)

This line has been traced at the Rigelian stage, where it has only a moderate intensity, and at the Crucian level, where it is only just visible. It apparently does not exist in Alnitamian stars.

HELIUM.

(Representative line 4026·34.)

The helium lines are conspicuous in all the spectra under discussion. The line in question is considerably stronger at the Crucian stage (where it attains a maximum intensity) than at the lower Rigelian level, and weakens (though only very gradually) from the Crucian through the various Alnitamian levels.

ASTERIUM.

(Representative line 4009·42.)

This line is appreciably stronger at the Crucian level (where it attains a maximum intensity) than at the lower Rigelian stage, and thins out in passing from the Crucian stage through the successive Alnitamian levels.

CARBON (I.).

(Representative line 4267·30.)

This is quite a good line at the Rigelian and Crucian levels, being somewhat stronger at the latter. It then weakens in passing to the Alnitamian (I.) stage, keeps about the same intensity at the Alnitamian (II.) stage, and then thins out to quite a weak line at the Alnitamian levels (III. and IV.).

NITROGEN (Ordinary Spark Lines).

(Representative line 3995·26.)

This is seen as a comparatively weak line in the Rigelian spectrum, appreciably strengthening at the Crucian (maximum at this stage) and then declines in going through the Alnitamian stages, being almost evanescent at the two higher levels.

OXYGEN.

(Representative line 4076·3.)

This line is only just traceable at the Rigelian stage, has developed considerably at the Crucian, strengthens a little more at the Alnitamian (I.) stage, keeps about the same intensity at the next Alnitamian (II.) level, and then declines considerably through the Alnitamian Stages III. and IV.

SILICIUM (III.).

(Representative line 4552·7.)

This occurs as a very weak line at the Rigelian stage, has developed considerably at the Crucian stage, further increases slightly at the Alnitamian (I.) level, and then gradually declines in intensity through the Alnitamian II., III., and IV. levels, at the top level being quite an inconspicuous line.

SULPHUR (Abnormal Lines).

(Representative line 4253·8.)

This is one of a pair of abnormal sulphur lines whose behaviour in stellar and terrestrial spectra have been discussed in a previous paper.*

It apparently does not exist at the Rigelian stage, is a fairly well-marked line at the Crucian level, increases slightly in intensity at the Alnitamian (I.) level, and then gradually declines through the higher Alnitamian Stages II., III., and IV.

SILICIUM (IV.).

(Representative line 4089·1.)

This line does not occur in the Rigelian spectrum. It exists as a comparatively weak line at the Crucian stage, has developed greatly in intensity at the Alnitamian I.

* Roy. Soc. Proc., Vol. 80, p. 50.

level, still further increasing at the Alnitamian (II.) level, where it attains a maximum intensity, and is one of the most conspicuous lines in the whole spectrum. It declines somewhat in intensity at the next Alnitamian (III.) stage, and further still at the Alnitamian (IV.) level. In all Alnitamian stars it occurs, however, as quite a conspicuous line.

CARBON (II.).

(Representative line $\left\{\begin{matrix}4647\cdot6\\4650\cdot8\end{matrix}\right\}$ double.)

This double, the occurrence of which in laboratory spectra of carbon taken under certain conditions, and in ϵ Orionis has been discussed in a former paper,* does not exist at the Rigelian level. There is a line of moderate intensity near the mean position of this double in Bellatrix (Crucian), but in this case the line is probably attributable more to oxygen λ 4649·2 than to carbon, although the latter origin may be involved to some extent. At the Alnitamian (I.) level the line has greatly increased in prominence, and assumes more the nature of a double. Here and at the higher Alnitamian levels there can be no doubt that the origin is, in the main, due to carbon, but it is possible that the oxygen line is also involved to some extent. At the Alnitamian (II.) stage the double carbon line reaches its maximum intensity, and is here one of the most conspicuous lines in the whole spectrum. It declines in intensity somewhat through the next two Alnitamian stages (III. and IV.), but in all Alnitamian stars it is, like the Group IV. line of Silicium λ 4089·1, quite a conspicuous line.

NITROGEN (Abnormal Lines).

(Representative line 4097·43.)

This line, whose behaviour in various nitrogen spectra and occurrence in ϵ Orionis has been referred to in a former paper,† does not exist at the Rigelian stage. It occurs as quite a weak line at the Crucian level, has considerably increased in intensity at the Alnitamian (I.) stage, still further develops at the Alnitamian (II.) stage, and declines in intensity through the two higher Alnitamian levels III. and IV.

PROTO-HYDROGEN.

(Representative line 4200·2.)

This line does not occur in the Rigelian and Crucian spectra, but comes in as a weak line at the Alnitamian (I.) level, and then gradually increases in intensity through the Alnitamian levels II., III., and IV. to the Argonian stage (ζ Puppis), where the proto-hydrogen lines are second only in prominence to those of hydrogen.

SPECIAL NOTES ON CERTAIN LINES.

λ 4069·7.

The line near this position in the Crucian (γ Orionis) spectrum is probably solely due to Oxygen λ 4070·04. At any rate the relative intensities of this

* Roy. Soc. Proc., Vol. 82, p. 541. † Roy. Soc. Proc., Vol. 82, p. 534.

line and the oxygen lines λλ 4072·40, 4076·08, in γ Orionis, are about the same as in the oxygen spark spectrum. In the Alnitamian stars, however—especially those of the higher levels—it appears certain that a strange line comes in slightly on the more refrangible side of the oxygen line λ 4070·04. Besides this slight difference in position, the line (or combination of lines) seems to be relatively too strong—as compared with the other oxygen lines λλ 4072·40, 4076·08—to be attributable to oxygen only in the Alnitamian stars. Search has been made through many laboratory spectra, especially those of various gases, with the object of finding a terrestrial line which would account for the stellar line, but with no success. None of the oxygen spectra, which have been photographed under varied conditions of current, shows any modification in the intensity of the most refrangible line, relative to the intensities of the other two lines of the oxygen triplet.

In Bellatrix the three oxygen lines are of about equal intensity, but higher up the stellar temperature scale, at the ζ Orionis stage, the line near λ 4069·7 is quite well marked, whereas the oxygen lines λλ 4072·40, 4076·08, are very weak. In this star, indeed, the characteristic appearance of the oxygen triplet as it occurs in γ Orionis, has greatly changed. It seems certain that this is due to the development in intensity of a strange line slightly more refrangible than the oxygen line λ 4070·04 and the simultaneous weakening of the oxygen lines λλ 4072·40, 4076·08.

RELATION OF ORION STARS TO WOLF-RAYET STARS.

There can be little doubt, from a study of the lines in the spectra of Wolf-Rayet stars, that, so far as their chemistry is concerned, they are more closely related to Orion stars (especially to the higher Alnitamian and the Argonian groups) than to those of any other class. Thus, in addition to the ordinary lines of hydrogen, the helium lines are undoubtedly present in the bright-line-star spectra, and the same remark applies to the lines of hydrogen which Professor Pickering discovered in the spectrum of ζ Puppis.

With the exception of Mg 4481, perhaps, these represent the only lines in bright-line-stars whose origin is known. As all the lines mentioned occur in the higher groups of Orion stars, it seems fairly certain that if we ignore the different nature of the lines—that is, absorption lines in Orion stars and radiation lines in Wolf-Rayet stars—the latter stars must be placed next to the Argonian group of the Kensington classification and on the upper side.

With regard to the several well-marked lines of Wolf-Rayet stars which have not yet been traced to any terrestrial origin none of these has with certainty been found in the spectra of the ordinary dark-line stars. Research with the definite object of tracing these lines to their terrestrial equivalents is very desirable. As all the bright-line-star lines (Mg λ 4481·3 excepted) whose origin is already known are due to gaseous substances, it would appear that the kind of research at first taken up should be on known gases subjected to varying laboratory conditions.

REFERENCE TO "UNKNOWN" LINES.

In the spectra of the Rigelian, Crucian and Alnitamian stars under discussion there now remain very few prominent lines which have not been definitely traced to their terrestrial equivalents. In a previous paper* a diagrammatic representation was given of the sequential intensities of various stellar lines in the type stars of the different groups in the Kensington classification. In this diagram, well-marked lines at λλ 4089, 4649 in Alnitamian spectra were referred to as "unknown" lines. These have since been identified with lines in terrestrial spectra, the first with a line of silicium, the other with a double line of carbon. These lines of the elements mentioned occur prominently in laboratory spectra only under particular conditions of current. Several other lines in Orion spectra, then of unknown origin, have since been traced to sulphur.†

REFERENCE TO DIAGRAMS AND PLATE.

I.—This shows diagrammatically the relation to each other of the various stages included in the Rigelian, Crucian and Alnitamian spectra under discussion. A representative line for each of the chemical forms has been taken and its sequential intensity shown in going through these various stages. Only the changes in intensity of the different lines as we pass from the lowest to the highest stage are meant to be portrayed. Thus the varying thicknesses along one horizon do not represent the relative intensities of the lines in the type star at that particular level. It will be noted that the range upwards from Rigel of some of the lines is quite a short one, but the majority of the chemical forms discussed are represented through nearly all the groups included in the helium stars. Proto-iron, apparently of short range in the diagram, extends, however, to the lower levels such as the Cygnian, Polarian, and Aldebarian groups, in the last of which its lines occur very weakly. The ordinary spark lines of sulphur, as represented by λ 4815·3, only occur, so far as present photographs enable one to judge, at successive levels Rigelian and Crucian, fairly well seen in the former but nearly evanescent in the latter.

II.—This plate shows a photographic comparison of the spectra of typical stars of the Rigelian, Crucian and Alnitamian groups of the Kensington classification.

The reproduced enlargements are on a scale 3·5 times the originals. The lines have been lengthened by an up-and-down motion of the original negatives. The typical lines of the various chemical elements represented in the spectra have been denoted on different horizons. The spectral types in which the lines of a particular element are most prominent have also been indicated on the left side of the plate. It may here be mentioned that of the so-called "new hydrogen" lines first found by Professor Pickering in ζ Puppis, only the first line in the

* Proc. Roy. Soc., Vol. 64, p. 399.

† Proc. Roy. Soc., Vol. 80, p. 50.

principal series (λ 4686)* had been traced in terrestrial spectra until Professor Fowler recently† obtained also the subordinate series lines at λλ 5410·5, 4541·3 and 4200·3 in his laboratory spectra.

III.—This gives a diagrammatic illustration of the behaviour in the Rigelian, Crucian and Alnitamian stars of the chief lines for which no laboratory equivalents have been found. Nearly all of these are of comparatively insignificant intensity, as practically all the outstanding lines in these spectra have been traced to their chemical origin.

* Roy. Soc. Proc., Vol. 74, p. 546.

† *Monthly Notices* (R.A.S.), Vol. 73, No. 2.

PART II.

ON THE LINE SPECTRUM OF α ORIONIS AND ITS RELATION TO THAT OF ARCTURUS AND THE FRAUNHOFERIC SPECTRUM.

Although a reduction of the lines in the spectrum of α Orionis (typical of Secchi's Group III. stars) has been given by Scheiner* (region λ 4294 to λ 4625), Pickering† (region λ 3933 to λ 4861) and Keeler‡ (region λ 4861 to λ 5914) very little has been published as to the chemical origins of the lines and their relation (from the point of view of both origin and intensity) to lines in the Fraunhoferic Spectrum. In fact, in Pickering's and Keeler's lists the chemical origins of the lines were not considered, only their intensities relatively to corresponding solar and stellar lines being indicated. In a Kensington publication,§ "On the Photographic Spectra of Some of the Brighter Stars," a reproduction on a large scale was given of the spectrum of α Orionis, and the chemical origins of the chief lines were indicated.

In view of the evidence adduced in recent years as to the close resemblance of sun-spot spectra to the spectra of some of the lower-type stars, it has been thought desirable to make a detailed comparison of the lines in the spectrum of α Orionis with those in the Fraunhoferic and Arcturian spectra, and note and analyse the differences in relative intensity which occur amongst lines in these spectra and also ascertain which chemical elements are chiefly involved in these affected lines and in what way their lines are affected.

Several good photographs have recently been obtained at Kensington of the spectrum of α Orionis with the two 6-inch Henry objective prisms, and the best of these has been directly compared with the Fraunhoferic spectrum and that of Arcturus, both photographed on the same scale, in the case of the Fraunhoferic spectrum a collimator having been introduced into the spectroscope.

The spectrum of α Orionis was first compared with the Fraunhoferic spectrum, and it was found that there were many changes in relative intensity of the lines which correspond in position in the two spectra. By the aid of Rowland's maps of the solar spectrum and his "Tables of Solar Wave-lengths," the solar lines which appear to be involved in the α Orionis lines have been ascertained, and are given in the following table. These, however, only apply to the lines showing some change on passing from sun to star. Those having about the same intensity in the two spectra have been omitted.

The first column gives the wave-lengths of the solar lines which have been considered as probably taking part in the formation of the stellar lines. These

* Scheiner's Spectroscopy (Frost's translation), p. 304.

† Annals, Harv. Coll. Obs., Vol. 28, Pt. I., p. 58.

‡ The Spectra of Stars of Secchi's Fourth Type. (Decennial Publications of Chicago University, Vol. 8, p. 120.

§ Phil. Trans., Vol. 184, Plate 28. 1893.

wave-lengths are given from Rowland's tables to the nearest hundredth of a tenth-metre. The second column gives the probable chemical origin of these solar lines. Rowland's origins have been adopted in general, and supplemented by origins found for some of Rowland's solar lines from a study of the enhanced lines of metals at Kensington. The last column is reserved for remarks, chiefly as to whether the lines are strengthened or weakened in passing from sun to star. From λ 4595 to λ 4940, the behaviour in Hale's sun-spot maps of the strengthened stellar lines has been added in the final column, thus giving a comparative statement of the way the same lines are affected in sun-spots and star. It has been considered better in an inquiry of this nature, where in many cases groups of fine individual lines in the solar spectrum are thrown together in the star and are there irresolvable, to notify the different grades of change by phrases such as "slightly strengthened," "strengthened," "considerably strengthened," "much strengthened," "very much strengthened," than by giving numerical intensities. The latter would probably be a better method if the stellar and solar spectra were of much larger dispersion, when the lines or groups could be much better split up into their component parts.

In cases where brackets are introduced they indicate that the Rowland's solar lines included in the brackets cannot be seen separately in the solar spectrum of low dispersion with which the stellar spectrum has been compared, but are those which are considered to be probably involved in the stellar lines of apparently corresponding position.

LINES WHICH ARE STRENGTHENED OR WEAKENED IN PASSING FROM SOLAR SPECTRUM TO THAT OF α ORIONIS.

Wave-lengths of Solar Lines involved in Stellar Lines (Rowland).	Origin of Lines involved.	Remarks, chiefly on whether the Lines are strengthened or weakened in passing from Solar Spectrum to α Orionis.
4318·82	Ca Mn?	Slightly strengthened.
4323·17	Un	This is a close bunch of five solar lines of unknown origin which in a solar spectrum of small dispersion looks like a well-marked line. In the spectrum of α Orionis of similar dispersion the bunch is weakened almost to evanescence.
4323·39	Un	
4323·67	Un	
4324·01	Un	
4324·14	Un	
4325·15	Sc	Considerably strengthened.
4325·94	Fe	
4326·92	Fe	
4327·24	Fe	
4328·08	Fe	Slightly strengthened.
4330·19	V	Group of weak solar lines. Collectively much strengthened in star.
4330·41	Un	
4330·87	p. Ti Ni	
4331·19	Un	
4332·99	V	Considerably strengthened.
4333·08	Un	
4333·93	La	Slightly strengthened.
4335·10	La	„ „
4337·22	Fe	Collectively slightly strengthened.
4337·73	Cr	
4338·08	p. Ti	
4338·43	Fe	
4339·62	Cr	Considerably strengthened.
4339·88	Cr	
4340·63	H	Hγ. Weaker than in sun.
4341·17	V	Much strengthened.
4341·53	p. Ti	
4343·33	Cr	Weakened.
4343·43	Fe	

Wave-lengths of Solar Lines involved in Stellar Lines (Rowland).	Origin of Lines involved.	Remarks, chiefly on whether the Lines are strengthened or weakened in passing from Solar Spectrum to α Orionis.
4344·45	p. Ti	Strengthened.
4344·67	Cr	
4347·40	Fe	Very much strengthened.
4347·70	Un	
4351·00	Ti	" " "
4351·22	Cr	
4352·91	Fe	Strengthened.
4353·04	V	
4354·78	Un	Slightly strengthened.
4355·26	? Ca	
4355·87 to 4357·07	Chiefly Un	Group of weak solar lines. Collectively slightly strengthened.
4358·67	Fe	Strengthened.
4358·88	Y Zr	
4359·78	Cr	"
4360·45	Un	Slightly strengthened.
4360·64	Ti	
4360·96	Fe Zr	
4361·95	? Sr	Nearly evanescent in sun. Distinct line in star.
4365·69	Un	Considerably strengthened.
4368·29	V	Very much strengthened.
4368·46	Ni	
4369·87	Ti	Slightly weakened.
4369·94	Fe	
4371·14	Zr	Slightly strengthened.
4371·22	Un	
4371·44	Cr	
4373·42	Cr	Much strengthened.
4373·73	Fe	
4373·95	V	
4375·10	V Mn Y	Considerably strengthened.
4379·40	V	" "
4383·72	Fe	Slightly strengthened and broadened.
4384·87 to 4385·55	V Cr La p. Fe	Bunch of solar lines, collectively slightly strengthened in star.
4389·41	Fe	Considerably strengthened.
4390·15	V	" "
4391·92	Cr	Strengthened.
4392·24	V?	
4395·20	p. Ti	"
4395·41	V	

Wave-lengths of Solar Lines involved in Stellar Lines (Rowland).	Origin of Lines involved.	Remarks, chiefly on whether the Lines are strengthened or weakened in passing from Solar Spectrum to α Orionis.
4398·18	Y	Rowland gives this as in Zircon but not in Zr. There is little doubt, however, that the real origin is yttrium. Much strengthened.
4400·56	Sc	Considerably strengthened.
4400·74	V	
4406·81	V	Strengthened.
4407·81	V	Considerably strengthened.
4407·87	Fe	
4408·36	V	
4408·58	Fe	
4408·68	V	
4410·88	Ni	Slightly strengthened.
4412·09	Un	Very much strengthened. Nearly evanescent in sun.
4412·30	V	
4412·45	Cr	
4413·76	Un	Slightly strengthened.
4415·29	Fe	" "
4415·72	Sc	
4416·64	V	Irresolvable group in star. Collectively slightly stronger than in sun.
4416·99	p. Fe	
4417·45	Ti	
4417·88	p. Ti	
4418·50	Ti	
4420·55	Un	Strengthened.
4421·73	V	Much strengthened.
4422·74	Fe Y	Strengthened.
4424·01	Fe?	"
4425·61	Ca	"
4426·20	V	
4427·27	Ti	"
4427·48	Fe	
4428·71	VCr	Slightly strengthened.
4430·36	Fe	Considerably strengthened.
4430·79	Fe	
4434·17	Ti	" "
4435·13	Ca	Strengthened.
4435·32	Fe	
4435·85	Ca	
4436·31	V	Much strengthened.
4436·52	Mn	
4438·01	V	Nearly evanescent in sun. Quite a strong line in star.
4440·01	Fe	Strengthened.
4441·88	V	"
4442·51	Fe	
4443·98	p. Ti	Weakened.

Wave-lengths of Solar Lines involved in Stellar Lines (Rowland).	Origin of Lines involved.	Remarks, chiefly on whether the Lines are strengthened or weakened in passing from Solar Spectrum to α Orionis.
4444·57	V Ti	Considerably strengthened.
4444·73	Fe Ti	
4447·89	Fe	Strengthened.
4449·31	Ti	Much strengthened.
4450·48	Zr Fe	Strengthened.
4450·65	p. Ti	
4451·75	Mn	Slightly strengthened.
4452·17	V	
4453·49	Ti	Much strengthened.
4453·88	Ti	
4457·60	Ti V Zr	Considerably strengthened.
4460·39	V	Very much strengthened.
4460·46	Mn	
4461·24	Mn	Close group of solar lines irresolvable in star. Collectively slightly strengthened.
4461·37	Fe Zr Ni	
4461·82	Fe	
4462·17	Fe Mn	
4462·52	V	
4462·62	Ni	
4463·57	Ti Ni	Considerably strengthened.
4464·62	p. Ti ?	Slightly strengthened.
4464·84	Mn	
4466·55	Ni	Strengthened.
4466·73	Fe	
4468·66	p. Ti	Weakened.
4469·32	Ti	Strengthened.
4469·55	Fe	
4469·73	Co	
4469·87	V	
4471·02	p. Ti	Very much strengthened.
4471·41	Ti	
4475·03	Ti	Much strengthened.
4479·55	Mn	Slightly strengthened.
4479·78	Fe	
4479·88	Ti	
4480·31	Fe	
4481·44	Ti p. Mg ?	Weakened.
4481·78	Fe	
4482·34	Fe	Collectively very much strengthened. Irresolvable in star but intensification seems to be more on the less refrangible side. Probably the Ti line is the one most strengthened.
4482·44	Fe	
4482·90	Ti Fe	
4484·39	Fe	Slightly strengthened.
4487·5	Un	Distinct but not very strong line in star. Impossible to say which of several very weak solar lines it is identical with.
4489·91	Fe	This is a very strong well-defined line in α Orionis, whereas in the sun there is only a group of lines all individually weak. Which particular line is chiefly involved in the intensification from sun to star it is impossible to say with the dispersion employed. This is one of the most outstanding lines in α Orionis in so far as the difference in intensity between stellar and solar lines is concerned.
4490·25	Fe Mn	
4492·48	Cr Fe	Strengthened.
4492·85	Un	
4494·74	Fe	Slightly strengthened.
4496·12	Un	Strong line in star covering position occupied by these solar lines. The middle of the stellar line, however, approximates more closely to the position of the Ti line than to either of the other two solar lines. Very much strengthened in star.
4496·32	Ti	
4497·02	Cr	
4501·95	Un	Strong line in star here. Weak lines in sun. The position of the stellar line is near that of the weak solar-V line.
4502·16	V	
4502·39	Mn	
4502·76	Fe ?	
4504·04	Mn	Strengthened.
4507·0	Un	Fairly well-marked in star. Apparently no counterpart in sun.
4508·46	p. Fe	Weakened.
4509·90	Un	Strengthened.
4512·91	Ti	Very much strengthened.
4518·20	Ti	Much strengthened.
4518·51	Un	
4518·87	Ti	
4520·16	Ni	Strengthened.
4520·40	p. Fe	
4522.69	Fe ?	Considerably strengthened.
4522·80	p. Fe	
4522·97	Ti	
4525·31	Fe	Weakened.
4527·49	Ti	Considerably strengthened.
4530·87	Cr	Strengthened.
4530·91	Cr	
4531·12	Fe ? Co	
4531·33	Fe	
4533·13	Un	,,
4533·23	Un	
4533·42	Ti	

Wave-lengths of Solar Lines involved in Stellar Lines (Rowland).	Origin of Lines involved.	Remarks, chiefly on whether the Lines are strengthened or weakened in passing from Solar Spectrum to α Orionis.
4534·14	p. Ti Co	Weakened.
4534·95	Ti	Considerably strengthened.
4535·74	Ti	„ „
4535·88	Cr	
4535·91	Zr	
4536·09	Ti	
4536·22	Ti	
4537·85	Un	Nearly evanescent line in sun. Distinct line in star but not very strong.
4539·95	Cr	Strengthened.
4540·17	V	
4540·67	Cr	Much strengthened.
4540·88	Cr	
4542·40	Zr	„ „
4542·60	Fe	
4542·79	Cr	
4544·79	Cr	Considerably strengthened.
4544·86	Ti	
4545·31	Un	
4545·51	Cr V	
4546·13	Fe Cr	Much strengthened.
4548·94	Ti	„ „
4552·63	Ti	Strengthened.
4552·73	Fe	
4554·21	Ba	„
4555·66	Ti	Slightly strengthened.
4556·06	p. Fe	
4556·31	Fe	
4559·2	Un	Rather weak line in star, apparently no counterpart in sun.
4560·10	Ni Ti	Strengthened.
4560·27	Fe	
4560·89	V	Well-marked line bordering previous line in star. Apparently no counterpart in sun.
4562·81	Ti	Nearly evanescent in sun. Very strong in star.
4563·60	Ti	Strengthened.
4563·94	p. Ti	
4565·69	Cr	Slightly strengthened.
4565·84	Fe Co	
4569·69	Cr	Strengthened.
4569·79	Cr	
4571·28	Mg	Irresolvable in star, and collectively much stronger than in sun.
4571·85	Cr	
4571·98	V	
4572·16	p. Ti	
4574·90	Fe	Very much strengthened. The strengthening seems to be more on the less refrangible side. Rather broad line, probably compound.
4575·29	Cr	
4577·36	V	Nearly evanescent line in sun. Very much strengthened in star.
4578·73	Ca	Slightly strengthened.
4578·91	V	
4580·23	Cr	Much strengthened.
4580·59	V	
4580·76	Fe Ni	
4581·58	Ca	Weakened.
4581·69	Co Fe	
4584·02	p. Fe	Irresolvable and rather broad line in star. Considerably strengthened, mostly on violet side.
4584·90	Fe	
4585·00	Un	
4586·05	Ca	Considerably strengthened.
4586·41	Cr	
4586·55	V	
4590·13	p. Ti	Weakened.
4591·57	Cr	Strengthened.
4591·69	Un	
4592·71	Ni	Weakened.
4592·84	Fe	
4594·30	V	Much strengthened.
4595·54	Fe	Weakened.
4595·27	Cr	
4596·13	Ni	
4596·25	Fe	

Wave-lengths of Solar Lines involved in Stellar Lines (Rowland).	Origin of Lines involved.	Remarks chiefly on whether the Lines are strengthened or weakened in passing from Solar Spectrum to α Orionis.	Behaviour in Hale's Sun-spot Spectra.
4597·93	Un	Slightly strengthened.	Weakened.
4598·05	Un		„
4598·30	Fe		Slightly weakened.
4600·28	Cr	Considerably strengthened.	No change.
4600·38	V		„
4600·54	Ni		Much weakened.
4600·93	Cr		Strengthened.
4602·18	Fe	Slightly strengthened	No change.
4603·13	Fe	Strengthened	Slightly strengthened.
4605·17	Ni	Weakened	Weakened.
4605·77	Un		„
4606·8	Un	Very strong line in star. Apparently no counterpart in sun.	Not in spot spectrum.

Wave-lengths of Solar Lines involved in Stellar Lines (Row-land).	Origin of Lines involved.	Remarks, chiefly on whether the Lines are strengthened or weakened in passing from Solar Spectrum to α Orionis.	Behaviour in Hale's Sun-spot Spectra.
4607·51	Sr	Strengthened - -	Considerably strengthened.
4607·83	Fe		No change.
4609·45	Un	Very weak in sun. Considerably strengthened in star.	,,
4614·10	Un	Considerably strengthened.	Slightly weakened.
4614·39	Fe?		Slightly strengthened.
4616·31	Cr	,, ,,	Considerably strengthened.
4617·45	Ti	Strengthened - -	Strengthened.
4618·97	Fe p. Cr	Weakened - - -	Much weakened.
4619·47	Fe	Much strengthened -	No change.
4619·71	Cr		,,
4619·85	V		Much strengthened.
4619·96	V		,,
4623·28	Ti	Strengthened - -	Strengthened.
4626·36	Cr	Considerably strengthened.	Much strengthened.
4626·72	Mn		No change.
4629·0 to 4631·0	—	Irresolvable band in star covering the limiting wave-lengths given. The solar lines in the same region include λλ 4629·52 (Ti–Co–p.Fe), 4630·31 (Fe), and several other very weak lines of unknown origin. Collectively strengthened.	No change.
4635·35	V	Strengthened - -	Strengthened.
4636·03	Fe		Slightly weakened.
4637·69	Fe	Weakened - -	Weakened.
4637·94	Cr		Strengthened.
4638·05	Ti		,,
4638·19	Fe		No change.
4639·54	Ti	Much strengthened -	Strengthened.
4639·68	Cr		,,
4639·85	Ti		,,
4640·12	Ti		,,
4646·35	Cr	,, ,,	Much strengthened.
4646·55	V		,, ,,
4650·19	Ti	Strengthened - -	Strengthened.
4650·49	Un		No change.
4651·46	Cr	,, -	Strengthened.
4652·34	Cr	Considerably strengthened.	Strengthened.
4656·64	Ti	Very much strengthened.	Much strengthened.
4659·6	Un	Weak line in star. Apparently no counterpart in Sun.	Very weak line in spot spectrum.
4661·71	Un	Slightly strengthened	Slightly weakened.
4662·15	Fe?		No change.
4664·96	Cr	Strengthened - -	Slightly strengthened.
4667·63	Fe	Much strengthened -	Collectively little or no change.
4667·77	Ti		
4667·94	Ni		
4672·51	Un	Weakened - -	Weakened.
4673·34	Fe		,,
4675·29	Ti	Strengthened - -	Strengthened.
4677·10	Ti	,, - -	Slightly strengthened.
4678·34	Cd	Weakened - -	Weakened.
4679·03	Fe		Slightly weakened.
4679·41	Un		,,
4680·32	Zn	Weakened - -	Weakened.
4680·48	Un		Slightly strengthened.
4680·66	Cr		,,
4682·09	Ti	Much strengthened -	Collectively much strengthened.
4682·30	Fe?		No change.
4682·53	Co		,,
4682·75	Fe?		
4685·45	Ca	Slightly strengthened -	Strengthened.
4686·40	Ni	Slightly weakened -	Weakened.
4687·57	Fe?	These lines are very weak in sun. There is a strong line in star (probably double), which apparently agrees in position with this group of solar lines. Which solar line is chiefly affected it is impossible to say. Possibly an altogether strange line in α Orionis.	Strengthened.
4687·98	Zr		,,
4688·36	Fe		Weakened.
4688·55	Un		,,
4688·86	Un		Strengthened.
4690·98	Ti	Very much strengthened.	Nearly evanescent in sun. Distinct but weak in spot.
4691·52	Ti	Considerably strengthened.	Collectively little or no change.
4691·60	Fe		
4691·78	Un		

Wave-lengths of Solar Lines involved in Stellar Lines (Row-land).	Origin of Lines involved.	Remarks, chiefly on whether the Lines are strengthened or weakened in passing from Solar Spectrum to α Orionis.	Behaviour in Hale's Sun-spot Spectra.
4693·85	Ti	Considerably strengthened.	Considerably strengthened.
4694·13	Ni Cr		Slightly strengthened.
4695·04	Fe ?	Strengthened - -	No change.
4695·33	Cr		Slightly strengthened.
4697·23	Cr	Slightly strengthened -	Strengthened.
4698·58	Co	Much strengthened -	Close group, collectively much strengthened.
4698·64	Cr		
4698·80	Cr		
4698·95	Ti		
4703·18	Mg	Weakened - - -	No change.
4703·99	Ni	Strengthened - -	,,
4706·73	V	Much strengthened -	Very slightly strengthened.
4707·46	Fe	Slightly strengthened	Collectively strengthened.
4707·67	Un		
4709·90	Mn	Much strengthened	Slightly strengthened.
4710·37	Ti		Collectively much strengthened.
4710·47	Fe		
4715·47	Ti	Very much strengthened. The strengthening seems to be nearer the position of the weak solar Ti line than the Ni line.	Distinct line in spot. Nearly evanescent in sun.
4715·95	Ni		Slightly strengthened.
4718·60	Cr	Slightly strengthened -	Considerably strengthened.
4719·69	Un	Strengthened - -	Slightly strengthened.
4722·80	Ti	Much strengthened -	Very much strengthened.
4723·29	Cr		Collectively considerably strengthened.
4723·36	Ti		
4724·59	Un	Slightly strengthened -	Slightly strengthened.
4727·58	Fe	Irresolvable band in star. Collectively strengthened.	Collectively strengthened.
4727·68	Mn		
4728·73	Fe		Strengthened.
4729·21	Fe ?		,,
4729·86	Fe ? Cr	Weakened - -	Slightly strengthened.
4730·21	Un		Slightly weakened.
4731·65	Fe ?	Collectively slightly strengthened.	No change.
4731·98	Ni		,,
4732·64	Ni		Slightly strengthened.

Wave-lengths of Solar Lines involved in Stellar Lines (Row-land).	Origin of Lines involved.	Remarks, chiefly on whether the Lines are strengthened or weakened in passing from Solar Spectrum to α Orionis.	Behaviour in Hale's Sun-spot Spectra.
4733·60	Ti	Considerably strengthened.	Collectively considerably strengthened.
4733·78	Fe		
4734·28	Fe ?		Slightly strengthened.
4736·03	Fe	Collectively slightly strengthened.	No change.
4736·96	Fe		Slightly strengthened.
4737·54	Cr		,,
4737·82	Fe ?		,,
4739·29	Mn	Strengthened - -	,,
4741·13	Un	Irresolvable band.	Strengthened.
4741·26	Fe ?		,,
4741·72	Fe	Collectively strengthened.	Slightly strengthened.
4742·98	Ti		Strengthened.
4744·57	Fe	Collectively strengthened.	Weakened.
4745·50	Cr		Slightly strengthened.
4745·99	Fe		,,
4748·33	Fe	Weakened - - -	Weakened.
4749·85	Co	Strengthened - -	Slightly strengthened.
4750·14	Fe ?		Slightly weakened.
4754·23	Mn	Collectively strengthened.	Considerably strengthened
4754·55	Co		No change.
4754·95	Ni		Slightly weakened.
4758·31	Ti	Much strengthened -	Strengthened.
4759·46	Ti	Very much strengthened.	Strengthened.
4761·29	Un	Considerably strengthened.	Slightly strengthened.
4761·72	Mn		,,
4762·57	Mn	Strengthened - -	Slightly strengthened.
4762·82	Ni		,,
4762·97	Un		,,
4773·01	Fe	,, - -	Strengthened.
4778·44	Ti	Considerably strengthened.	,,
4779·63	Fe	Slightly strengthened	Considerably strengthened.
4780·17	Co		Slightly strengthened.
4781·91	Ti	Much strengthened -	Much strengthened.
4784·5	Un	Well marked line in star. Apparently no counterpart in sun.	Very weak line in spot.
4788·02	Fe ?	Strengthened - -	Strengthened.

Wavelengths of Solar Lines involved in Stellar Lines (Rowland).	Origin of Lines involved.	Remarks, chiefly on whether the Lines are strengthened or weakened in passing from Solar Spectrum to α Orionis.	Behaviour in Hale's Sun-spot Spectra.
4789·53	Cr	Considerably strengthened.	Considerably strengthened.
4789·85	Fe		Strengthened.
4792·70	Ti Cr	Strengthened - -	Considerably strengthened.
4793·05	Co		Slightly strengthened.
4794·55	Un	Strengthened - -	Strengthened.
4796·37	Cr-Ti	Much strengthened -	Considerably strengthened.
4797·09	V		Strengthened.
4799·98	Ti	Considerably strengthened.	Considerably strengthened.
4800·84	Ni Fe	„ „	Slightly strengthened.
4801·21	Cr		„
4805·19	Un	Strengthened. Head of Ti fluting here.	Collectively weakened.
4805·29	p. Ti		Slightly strengthened.
4805·61	Ti		
4808·73	Ti	Strengthened - -	No change.
4808·87	Fe		
4810·72	Zn	Weakened - - -	Weakened.
4812·18	Ni	Considerably strengthened.	No change.
4812·43	Ti		Slightly strengthened.
4815·5	Un	Distinct line in star. Apparently no counterpart in sun.	Apparently no line in sun or spot.
4820·59	Ti	Considerably strengthened.	Strengthened.
4823·70	Mn	Slightly strengthened	Strengthened.
4824·33	Fe p. Cr		No change.
4825·67	Ti	Strengthened - -	Slightly strengthened.
4827·64	V	Very much strengthened.	Very much strengthened.
4827·80	Ti		
4829·21	Ni	Slightly strengthened	No change.
4829·53	Cr		
4831·83	V	These two lines, nearly evanescent in the sun, are very strong in the star, so much so as to fill up the space between the two solar lines λλ 4831·37, 4832·91 and collectively form the most conspicuous line in this part of the stellar spectrum, equalling in intensity H β.	Much strengthened.
4832·62	V		„

Wavelengths of Solar Lines involved in Stellar Lines (Rowland).	Origin of Lines involved.	Remarks, chiefly on whether the Lines are strengthened or weakened in passing from Solar Spectrum to α Orionis.	Behaviour in Hale's Sun-spot Spectra.
4836·06	Fe	Strengthened - -	Slightly strengthened.
4836·31	Ti		„
4848·44	p. Cr	Collectively strengthened.	Weakened.
4848·61	Ti		Strengthened.
4849·08	Fe		Slightly strengthened.
4849·36	Un		Weakened.
4851·69	Ca V	Very much strengthened.	Very much strengthened.
4861·53	H	H β. Slightly weakened	Weakened.
4864·92	V	Very much strengthened.	Very much strengthened.
4868·06	Co	Considerably strengthened.	No change.
4868·45	Ti		Considerably strengthened.
4870·32	Ti	Slightly strengthened -	„
4871·00	Ni Cr	Collectively strengthened.	No change.
4871·51	Fe		Strengthened.
4872·11	Un		„
4872·33	Fe		„
4875·67	V	Much strengthened -	Very much strengthened.
4878·31	Ca	Slightly strengthened	Strengthened.
4878·41	Fe		„
4881·13	Ti	Very weak in sun. Strengthened in star.	Slightly strengthened.
4881·74	V	Much strengthened -	Very much strengthened.
4881·90	Un		
4885·26	Ti	Considerably strengthened.	Much strengthened
4885·62	Fe		No change.
4887·19	Ni Cr	Strengthened - -	Collectively slightly strengthened.
4887·38	? Fe		
4894·0	Un	Stellar line not very strong. Apparently no counterpart in sun.	Very weak in Hale's sun, lacking in spot.
4896·63	Fe	Slightly strengthened.	No change.
4900·10	Ti La	Much strengthened -	Slightly strengthened.
4900·30	Y ?		No change.
4903·50	Fe	Strengthened - -	Strengthened.
4904·60	Un	Strengthened - -	No change.
4905·31	Fe ?		„
4909·57	Fe	Collectively strengthened.	Slightly weakened
4910·20	Fe		No change.
4910·51	Fe		„
4910·75	Fe		„
4911·96	Fe	Weakened - -	Collectively slightly weakened.
4912·20	Ni		

Wave-lengths of Solar Lines involved in Stellar Lines (Row-land).	Origin of Lines involved.	Remarks, chiefly on whether the Lines are strengthened or weakened in passing from Solar Spectrum to α Orionis.	Behaviour in Hale's Sun-spot Spectra.
4913·80	Ti	Considerably strengthened.	Slightly strengthened.
4914·15	Un		Slightly weakened.
4921·96	La Ti	Much strengthened -	No change.
4924·11	p. Fe	Weakened - - -	Much weakened.
4924·96	Fe	Strengthened - -	No change.
4925.75	Ni		,,
4927·60	Fe	Slightly strengthened	Slightly weakened.
4928·05	Fe		Weakened.
4928·51	Ti		Slightly strengthened.
4933·51	Fe	Strengthened - -	Weakened.
4934·25	Ba		Slightly weakened.
4937·53	Ni ?	Much strengthened -	Weakened.
4937·90	Ti		Strengthened.
4939·87	Fe	Much strengthened. Star line apparently less refrangible than the Fe line.	Slightly strengthened.
4940·26	Un		

PROBABLE ORIGINS OF LINES INVOLVED IN THE "MUCH STRENGTHENED" AND "VERY MUCH STRENGTHENED" LINES IN PASSING FROM THE SOLAR SPECTRUM TO THAT OF α ORIONIS.

Below are given the probable origins of the solar lines thought to be involved in the "much strengthened" and "very much strengthened" lines in passing from sun to star. Each bracket represents a different stellar line. Where a bracket contains more than one symbol it means that the stellar line has been considered to involve lines of more than one substance, these lines, although probably separable in large-dispersion solar photographs, having, in the case of the stellar spectra, coalesced into lines of compound origin. The symbol "Un" denotes a line of unknown origin. The letters "m.s." and "v.m.s." after a bracket denotes "much strengthened" or "very much strengthened," that is, in passing from solar to stellar spectrum. The wave-lengths of these lines are not here added, but could be readily extracted from the previous table if necessary. It is here intended to discuss only the chief substances involved in these strengthened lines.

V, Un, Ti, Ni — m.s.	Cr, Fe, V — m.s.	Ti — m.s.	Un, Ti, Cr — v.m.s.
V, Ti — m.s.	Y — m.s.	Ti — m.s.	Un, V, Mn — m.s.
Fe, Un — v.m.s.	Un, V, Cr — v.m.s.	V, Mn — v.m.s.	Ti — v.m.s.
Ti, Cr — v.m.s.	V — m.s.	p. Ti, Ti — v.m.s.	Ti, Un — m.s.
V, Ni — v.m.s.	V, Mn — m.s.	Ti — m.s.	Cr — m.s.
	V — m.s.	Fe, Ti — v.m.s.	Fe, Cr — m.s.
		Mn, Fe — v.m.s.	

Fe, Cr } m.s.
Ti } m.s.
Ti } m.s.
Mg, Cr, p. Ti } m.s.
Fe, Cr } v.m.s.
V } v.m.s.
Cr, V, Fe Ni } v.m.s.
V } m.s.
Un } v.m.s.
Fe, Cr, V } m.s.

Ti, Cr } m.s.
Cr } m.s.
Ti } v.m.s.
Fe, Ti, Ni } m.s.
Ti, Fe, Co } m.s.
Zr, Fe, Un } m.s.
Ti } v.m.s.
Co, Cr, Ti } m.s.

V } m.s.
Mn, Ti, Fe } m.s.
Un, Ni } v.m.s.
Ti, Cr } m.s.
Ti } m.s.
Ti } v.m.s.
Ti } m.s.
Un } m.s.
Cr, Ti, V } m.s.
V, Ti } m.s.

V } v.m.s.
Ca, V } v.m.s.
V } v.m.s.
V } m.s.
V, Un } m.s.
Ti La, Y } m.s.
La Ti } m.s.
Ni, Ti } m.s.
Fe, Un } m.s.

An analysis of these origins is given in the following table. The total number of "much strengthened" and "very much strengthened" lines is sixty-one.

Element.	Number of Well-strengthened Lines in which involved.	Percentage.	Element.	Number of Well-strengthened Lines in which involved.	Percentage.
Ti	29	48	Mn	5	8
V	21	34	Co	2	3
Ti *or* V	46	75	La	2	3
Cr	16	26	Y	2	3
Unknown	14	23	Mg	1	2
Fe	14	23	Ca	1	2
Ni	6	10	Zr	1	2

From this analysis it is at once evident that the elements titanium and vanadium are chiefly involved in the strengthening of lines in passing from the solar spectrum to that of α Orionis. No less than 75 per cent. of the "much strengthened" and "very much strengthened" lines involve either vanadium or titanium. Next in order of prominence comes chromium. Iron occupies rather an insignificant place in this connection, as only 23 per cent. of strengthened lines involve this element; and, taking into consideration the fact that Fe lines are far more numerous in the Fraunhoferic spectrum than are the lines of other elements, it is evident that iron cannot be considered to take nearly so large a part in these strengthened lines as do Ti, V, or Cr. It will not be too much to say that in cases of strengthened stellar lines which apparently involve several solar lines of different origins, when these include either V or Ti it is quite probable that the lines of these elements are chiefly concerned in the strengthening of the lines in passing from sun to star.

It has been thought desirable to extract from the detailed records the titanium lines which are involved in the greatly strengthened stellar lines and see if any particular type of line is affected. The following table gives the wave-lengths, solar intensities, spark and arc intensities of the titanium lines under discussion. The fifth column indicates whether the stellar line involving the titanium line is "much strengthened" (m.s.) or "very much strengthened" (v.m.s.)

TITANIUM LINES INVOLVED IN THE "MUCH-STRENGTHENED" AND "VERY-MUCH-STRENGTHENED" LINES IN α ORIONIS.

Wave-lengths of Ti-Solar Lines (Rowland).	Solar Intensity.	Intensity (Exner and Haschek).		Whether "Much Strengthened" or "Very much Strengthened" in Star.	Remarks.	Wave-lengths of Ti-Solar Lines (Rowland).	Solar Intensity.	Intensity (Exner and Haschek).		Whether "Much Strengthened" or "Very much Strengthened" in Star.	Remarks.
		Spark. Max. 100.	Arc. Max. 20.					Spark. Max. 100.	Arc. Max. 20.		
4351·00	1	2	0	v.m.s.		4640·12	1	2	4	m.s.	
4449·31	2	5	10	m.s.		4656·64	3	3	8	v.m.s.	
4453·49	2	3	8	m.s.		4667.77	3	3	10	m.s.	
4453·88	1	3	8	m.s.		4682·09	3	3	10	m.s.	
4471·41	0	2	5	v.m.s.		4698·95	1	2	5	m.s.	
4475·03	0	2	3	m.s.		*4710·37	00	—	3	m.s.	
4482·90	1	2	3	v.m.s.	Solar line partly due to Fe.	4722·80	0	—	—	m.s.	
4496·32	1	3	10	v.m.s.		4723·36	00	—	3	m.s.	
4512·91	3	4	15	v.m.s.		4758·31	1	10	10	m.s.	
4518·20	3	4	15	m.s.		4759·46	2	10	10	v.m.s.	
4518·87	0	1	3	m.s.		4796·37	00	2	—	m.s.	Solar line partly due to Cr.
4548·94	2	3	15	m.s.		4827·80	00	—	—	v.m.s.	
4562·81	00	1	3	v.m.s.		4900·10	2	4	5	m.s.	Solar line partly due to La.
4639·54	2	2	4	m.s.		4921·96	1	2	—	m.s.	,,
4639·85	2	2	4	m.s.							

* Beyond this point the intensities are Eder and Valenta's.

It will be seen from the table that the titanium lines under discussion are not confined to any particular solar intensity. The range of solar intensity of all the titanium-solar lines given by Rowland is from 0000 to 6, and the preceding list gives a range of 000 to 3. A glance down the columns giving spark and arc intensities shows that the lines are almost invariably stronger in the arc than in the spark, thus being of the opposite type of line from the enhanced lines, which are represented in some of the higher stellar types, such as Cygnian and Sirian.

The laboratory photographs have been carefully examined, but do not furnish satisfactory evidence that those lines of titanium which appear to be much

strengthened in α Orionis have any special behaviour under certain conditions which separate them, as a class, from other titanium lines. Possibly some research on titanium lines occurring under conditions of temperature between those of the ordinary electric arc and those of the oxy-hydrogen blowpipe flame may reveal some particular behaviour of the titanium lines in question.

TITANIUM LINES INVOLVED IN THE α ORIONIS LINES CLASSED AS "CONSIDERABLY STRENGTHENED" AND "STRENGTHENED" IN PASSING FROM SOLAR SPECTRUM.

Wave-Length of Ti-Solar Lines (Rowland).	Intensity in Sun.	Intensity (Exner and Haschek). Spark. Max. 100.	Intensity (Exner and Haschek). Arc. Max 20.	Order of Strengthening in α Orionis. s = Strengthened, c.s = Considerably Strengthened.	Remarks.
4427·27	2	4	10	s.	
4434·17	0	3	5	c.s.	
4444·57	00	1	1	c.s.	Solar line partly due to V.
4444·73	2	1	—	c.s.	Solar line partly due to Fe.
4457·60	2	5	15	c.s.	Solar line partly due to VTr.
4463·57	0	1	8	c.s.	Solar line partly due to Ni.
4469·32	1	1	—	s.	
4522·97	2	4	15	c.s.	
4527·49	3	4	15	c.s.	
4533·42	4	5	20	s.	
4534·95	4	4	15	c.s.	
4535·74	3	3	8	c.s.	
4536·09	2	—	5	c.s.	
4536·22	2	4	5	c.s.	
4544·86	3	3	15	c.s.	
4552·63	2	4	15	s.	
4560·10	0	1	3	s.	Solar line partly due to Ni.
4563·60	00	—	2	s.	
4617·45	3	4	12	s.	
4623·28	2	3	8	s.	
4650·19	0	2	3	s.	
4677·10	00	—	—	s.	
4691·52	1	2	5	c.s.	
4693·85	0	1	2	c.s.	
* 4733·60	00	—	—	c.s.	
4742·98	1	4	4	s.	
4778·44	00	2	2	c.s.	
4792·70	2	3	—	s.	
4799·98	1	3	2	c.s.	
4805·61	0	8	3	s.	
4808·73	00	—	—	s.	
4812·43	0000	—	—	c.s.	
4820·59	1	3	3	c.s.	
4825·67	000	—	—	s.	
4848·61	0000	2	—	s.	
4868·45	0	3	4	c.s.	
4881·13	000	2	—	s.	
4885·26	2	4	5	c.s.	
4913·80	2	4	4	c.s.	

* From this point the intensities are Eder and Valenta's.

The table shows that there appears to be no particular class of Ti-solar line involved. The range in solar intensity of titanium-solar lines, according to Rowland's tables, is 0000 to 6, and in the preceding table titanium lines will be found of all solar intensities varying from 000 to 4.

A glance at the comparative intensities in spark and arc will show that in nearly all cases the titanium lines under discussion are stronger in arc than spark, that is, they are of just the opposite kind to the enhanced lines, which in general weaken in passing from the Sun to lower stellar types such as Arcturus and α Orionis. Here again, however, the differences between spark and arc intensity vary from $+5$ to -15, which also goes to show that, so far as our present knowledge of titanium spectra is concerned, it is not one particular class of line which is involved in the "strengthened" and "considerably strengthened" lines from Sun to star.

Although, then, it is well established that titanium lines play an important part in the strengthened lines in passing from the solar spectrum to that of α Orionis, our present knowledge of the titanium laboratory spectra does not throw much light on the exact conditions under which the titanium vapours exist in the absorbing atmosphere of α Orionis. Some titanium lines are strongly affected, others are not affected at all or only slightly so, and reference to laboratory spectra has shown that these two sets of titanium lines—of different stellar behaviour—cannot yet be separated into two distinct classes in so far as their behaviour in laboratory spectra is concerned.

As it was thought possible that the vanadium lines, analysed in the same way in which the titanium lines have been done, might show a closer connection between lines affected in the stellar photographs (α Orionis) and lines of special behaviour in the laboratory photographs, such an analysis has been made. The following table gives the vanadium lines which are involved in the "very much strengthened" and "much strengthened" lines in passing from solar spectrum to that of α Orionis.

VANADIUM LINES WHICH ARE "VERY MUCH STRENGTHENED" OR "MUCH STRENGTHENED" IN PASSING FROM THE SOLAR SPECTRUM to THAT OF α ORIONIS.

Wave-length.	Solar Intensity (Rowland).	Intensity (Exner and Haschek).		Order of Strengthening. v.m.s. = Very much Strengthened. m.s. = Much Strengthened.	Remarks.	Wave-length.	Solar Intensity (Rowland).	Intensity (Exner and Haschek).		Order of Strengthening. v.m.s. = Very much Strengthened, m.s. = Much Strengthened.	Remarks.
		Spark. Max.50.	Arc. Max.30.					Spark. Max.50.	Arc. Max.30.		
4330·19	0	8	10	m.s.		4438·01	0	5	10	v.m.s.	
4341·17	0	10	10	m.s.		4460·39	0	10	10	v.m.s.	
4368·29	0	3	4	v.m.s.		4502·16	00	5	4	m.s.	
4373·95	0	3	2	m.s.		4560·89	00	10	8	m.s.	
4412·30	00	3	4	v.m.s.		4571·98	00	10	4	m.s.	
4421·73	0	5	8	m.s.		4577·36	0	8	8	v.m.s.	
4436·31	0	5	1	m.s.		4580·59	1	10	8	m.s.	

Wave-length.	Solar Intensity (Rowland).	Intensity (Exner and Haschek). Spark. Max.50.	Intensity (Exner and Haschek). Arc. Max.30.	Order of Strengthening. v.m.s. = Very much Strengthened. m.s. = Much Strengthened.	Remarks.
4594·30	2	10	10	m.s.	
4619·85	0000	4	6	m.s.	Not separated by Exner and Haschek.
4619·96	00			m.s.	
* 4706·73	0	4	10	m.s.	
4797·09	000	5	6	m.s.	
4827·64	000	5	8	v.m.s.	
4831·83	00	4	7	v.m.s.	
4832·62	00	4	5	v.m.s.	
4851·69	1	6	8	v.m.s.	Solar line partly due to Ca.
4864·92	0	8	6	v.m.s.	
4875·67	1	10	8	m.s.	
4881·74	2	10	8	m.s.	

* From this point the spark and arc intensities are Eder and Valenta's.

An analysis of the solar and laboratory intensities of the lines in the preceding table shows that the great majority of the lines are weak in the sun and are stronger in the arc than the spark. In this they are in agreement with the vanadium lines which are much widened in sun spots. These are nearly invariably weak solar lines, and, in general, stronger arc than spark lines, though it must be mentioned that there are many vanadium lines of the latter class which are not strongly affected in sun-spot spectra.

It is fairly evident that our present knowledge of the vanadium laboratory spectra does not throw much light on the selective effect which takes place in connection with those vanadium lines which are well strengthened in sun spots and α Orionis as compared with the solar spectrum.

As before remarked about the titanium lines, it is probable that further research on laboratory spectra under temperature conditions lower than those of the arc would show that there is a selective behaviour of some of the vanadium lines, which would explain the fact that certain vanadium lines are far more conspicuously affected in sun-spot spectra and lower-type star spectra than are others.

As the analysis of the solar and laboratory (spark and arc) intensities of the vanadium and titanium lines has not thrown much light on the conditions in sun-spot vapours and the absorbing vapours of the lower-type stars, it has not been thought worth while to give a similar analysis for other elements such as chromium and iron, some of the lines of which, although affected, are not so conspicuously affected as the vanadium or titanium lines.

BEHAVIOUR OF ENHANCED LINES IN PASSING FROM THE SOLAR SPECTRUM TO THAT OF α ORIONIS.

It has been shown by Professor Fowler* that the enhanced lines of iron and titanium, which form such a prominent feature of the spectra of such stars as

* Monthly Notices, Vol. 66, p. 361, 1906.

α Cygni and Sirius, weaken in general in sun-spot spectra, as compared with their intensity in the Fraunhoferic spectrum.

With the small dispersion of the Kensington two-prism spectra of the sun and α Orionis, the enhanced lines in general are not sufficiently isolated from other lines as to enable us to trace their behaviour in passing from the solar to the stellar spectrum. There are a few, however, which are sufficiently isolated as to be without contamination from neighbouring lines, and the behaviour of these in the stellar spectrum has been specially noted. The results are given in the following list.

ENHANCED LINES IN SOLAR AND α ORIONIS SPECTRA.

λ.	Origin.	Behaviour from Sun to α Orionis.	λ.	Origin.	Behaviour from Sun to α Orionis.
4444·00	p. Ti	Weakened.	4558·83	p. Cr	No change.
4468·66	p. Ti	„	4588·38	p. Cr	„ „
4501·45	p. Ti	„	4590·13	p. Ti	Weakened.
4508·45	p. Fe	„	4924·11	p. Fe	„
4515·51	p. Fe	No change.			

Although the enhanced lines which could be properly investigated are few in number, the foregoing result is sufficient to show that, like their behaviour in sun-spot spectra, the enhanced lines weaken in passing from the solar spectrum to α Orionis, which is additional evidence that the conditions of the vapours in sun spots are not very dissimilar to those in the absorbing atmosphere of such stars as α Orionis.

COMPARISON OF ARCTURUS AND α ORIONIS SPECTRA.

In a previous Kensington publication* it has been shown from a comparative study of the spectra of the sun and Arcturus that the latter must be placed on a lower scale than the sun in a temperature classification of celestial bodies. As the fluted spectrum (shown by Professor Fowler to be chiefly due to titanium oxide) is considerably more developed in α Orionis than in Arcturus it is most probable that the temperature conditions in the absorbing atmosphere of α Orionis are, in general, lower than those existing in Arcturus. To test this point further it has been thought desirable to compare in detail the line absorption in the two stars, and note and study the changes which occur in the relative intensities of the lines and investigate the chemical elements which are chiefly concerned in the lines showing considerable changes. The spectra compared were taken with the two 6-inch Henry prisms of 45° angle. The following table shows the lines which are affected in passing from the spectrum of Arcturus to that of α Orionis.

* On the chemical origin of various lines in solar and stellar spectra. (Published by the Solar Physics Committee, 1910.)

The lines which are unaffected, *i.e.*, equally prominent in both spectra, have been omitted. The first column gives the wave-lengths of the solar lines which are considered to be involved in the stellar lines which show any change. The second column gives the probable origin of these solar lines. The third column is reserved for remarks on the nature of the change in the intensity of the stellar lines, and for any other necessary notes. For the region of spectrum which is comparable with Hale's maps of sun-spot spectra, another column is added showing the behaviour of the same lines in sun-spot spectra.

LINES AFFECTED IN PASSING FROM ARCTURUS TO α ORIONIS.

Wave-Lengths of Solar Lines involved in Stellar Lines (Rowland).	Origin of Lines involved.	Remarks, chiefly on whether strengthened or weakened in passing from Arcturus to α Orionis Spectrum.
4316·96	Ti ?	Slightly weakened.
4318·82	Ca Mn ?	Strengthened.
4323·17 to 4324·14	All unknown	Bunch of several individually weak solar lines, all of unknown origin. They are quite well marked collectively in Arcturus, but in α Orionis have weakened.
4341·53	p. Ti	Weakened.
4343·37	Cr	Considerably weakened.
4343·43	Fe	
4343·86	Fe	
4344·45	p. Ti	Slightly strengthened.
4344·67	Cr	
4347·40	Fe	Very much strengthened.
4347·70	Un	
4354·78	Un	Slightly weakened.
4363·27	Cr	Weakened.
4363·46	Un	
4364·20	Un	Strengthened.
4364·35	Un	
4368·29	V	Very much strengthened.
4368·46	Ni	
4368·80	V	
4369·87	Ti	Weakened.
4369·94	Fe	
4372·90	Un	Strengthened.
4373·01	Un	
4373·15	Fe ?	
4376·11	Fe	Strengthened.
4379·40	V	Considerably strengthened.
4380·88	Un	Considerably weakened.
4390·15	V	Considerably strengthened.
4396·01	Ti	Strengthened.
4407·81	V	Inseparable in star. Strengthened.
4407·87	Fe	
4408·36	V	
4408·58	Fe	
4408·68	V	
4439·96	V	Weakened.
4430·07	La	
4430·22	La	
4430·36	Fe	
4430·79	Fe	
4437·73	Un	Strengthened.
4438·01	V	
4445·64	Fe	Slightly strengthened.
4449·31	Ti	Very slightly strengthened.
4450·48	Zr Fe	Strengthened.
4450·65	p. Ti	
4453·49	Ti	Slightly strengthened.
4453·88	Ti	
4454·95	Ca Zr	Weakened.
4455·49	Mn Ti	Strengthened.
4059·92	V	Considerably strengthened.
4460·39	Un	
4460·46	Mn V	
4471·02	p. Ti	Considerably strengthened.
4471·41	Ti	
4472·88	Fe	Weakened.
4472·97	Mn	
4473·10	Ni ?	
4479·55	Mn	"
4479·78	Fe	
4479·88	Ti	
4480·31	Fe	
4482·34	Fe	Considerably strengthened.
4482·44	Fe	
4482·90	Ti Fe	

Wave-Lengths of Solar Lines involved in Stellar Lines (Rowland).	Origin of Lines involved.	Remarks, chiefly on whether strengthened or weakened in passing from Arcturus to α Orionis Spectrum.
4489·91 4490·25	Fe Fe Mn	Very much strengthened in α Orionis. This is about the most affected line in the whole spectrum in passing from the sun or Arcturus to α Orionis. It is quite possible that the line in α Orionis is not the counterpart of either of the solar lines, but is due to something entirely strange.
4494·74	Fe	Slightly weakened.
4496·13 4496·32 4497·02	Un Ti Cr	Considerably strengthened.
4499·07 4499·31	Mn Un	Slightly weakened.
4501·45 4501·95 4502·16 4502·39 4502·76	p. Ti Un V Mn Fe ?	Considerably stronger than corresponding line in Arcturus and apparently covering the positions occupied by solar lines mentioned.
4507·00	V Ti	Rather diffuse line considerably strengthened. Rowland gives no origin for the weak solar lines near here, but the intensification is probably due to the Ti line λ 4506·51 combined with V lines $\lambda\lambda$ 4506·40, 4506·73.
4512·91	Ti	Considerably strengthened.
4518·20 4518·51	Ti Un	Slightly strengthened.
4525·31	Fe	Weakened.
4526·58 4526·63 4526·73	Un Cr Fe	,,
4527·49	Ti	Considerably strengthened.
4528·80	Fe	Slightly weakened.
4529·66 4529·73 4529·85 4530·02	Un Un Fe Cr	Slightly weakened.
4533·13 4533·22 4533·42	Un Un Ti	Strengthened.
4545·51	Cr V	Much strengthened.
4548·94	Ti	,, ,,
4549·64 4549·81	p. Fe p. Ti Co	Slightly weakened.
4554·21	Ba	Slightly strengthened.
4560·10 4560·27	Ni Ti Fe	Slightly strengthened.
4562·81	Ti	Very much strengthened.
4563·60 4563·94	Ti p. Ti	Slightly strengthened collectively.
4565·69 4565·84	Cr Fe Co	Slightly weakened.
4568·50 4568·94	Un Fe	Weakened.
4577·36	V	Much strengthened.
4580·23 4580·59 4580·76	Cr V Fe Ni	Slightly strengthened.
4581·58 4581·69	Ca Co Fe	Considerably weakened.
4584·02 4584·90 4585·00	p. Fe Fe Un	Considerably strengthened.

Wave Lengths of Solar Lines involved in Stellar Lines (Rowland).	Origin of Lines involved.	Remarks, chiefly on whether strengthened or weakened in passing from Arcturus to α Orionis.	Behaviour in Hale's Sun-spot Spectra.
4586·05 4586·41 4586·55	Ca Cr V	Slightly strengthened.	
4592·71 4592·84	Ni Fe	Weakened.	
4594·30	V	Considerably strengthened.	
4595·54 4595·77 4596·13 4596·25	Fe Cr Ni Fe	Weakened - -	Weakened. Slightly weakened. Much weakened. Weakened.
4603·13	Fe	Strengthened - -	Slightly strengthened.
4606·8	Un	Very much strengthened.	No line in spot or sun.
4607·51 4607·83	Sr Fe	Strengthened - -	Considerably strengthened. No change.
4609·45	Un	,, - -	,, ,,
4611·37 4611·47	Cr Fe	Slightly weakened -	,, ,, ,, ,,

Wave-lengths of Solar Lines involved in Stellar Lines (Row-land).	Origin of Lines involved.	Remarks, chiefly on whether strengthened or weakened in passing from Arcturus to α Orionis.	Behaviour in Hale's Sun-spot Spectra.
4613·39	Fe	Slightly strengthened	Little or no change.
4613·54	Cr		,, ,,
4614·10	Un		Slightly weakened.
4614·39	Fe?	,, ,, -	Slightly strengthened.
4617·45	Ti	Considerably strengthened.	Strengthened.
4623·28	Ti	Strengthened - -	,,
4629·52	Ti Co [p. Fe	Strengthened - -	No change.
4630·31	Fe		,,
4646·35	Cr	,, - -	Much strengthened.
4646·55	V		,,
4647·62	Fe	Weakened - - -	Weakened.
4651·46	Cr	Strengthened - -	Considerably strengthened.
4652·34	Cr		,,
4654·67	Fe	Slightly weakened -	No change.
4654·80	Fe		,,
4654·91	Cr		,,
4656·64	Ti	Much strengthened -	Much strengthened.
4659·6	Un	Weak line in α Orionis. No counterpart in Arcturus.	No line in sun or spot.
4661·71	Un	Slightly strengthened	Slightly weakened.
4662·15	Fe ?		No change.
4663·49	Cr	Weakened - -	,,
4664·00	Cr		,,
4664·97	Cr	Strengthened - -	Slightly strengthened.
4672·51	Un	Weakened - -	Weakened.
4673·35	Fe		,,
4673·46	Un		,,
4678·35	Cd	,, - -	,,
4679·03	Fe		Slightly weakened.
4679·41	Un		,,
4680·32	Zn	Considerably weakened.	Weakened.
4680·48	Un		Slightly strengthened.
4680·66	Cr		No change.
4682·09	Ti	Considerably strengthened.	Collectively strengthened.
4682·29	Fe ?		
4682·53	Co		No change.
4682·75	Fe ?		,,
4687·57	? Fe	Strengthened - -	Strengthened.
4687·98	Zr		,,
4688·36	Fe		Weakened.
4688·55	Un		,,
4688·86	Un		Strengthened.
4690·98	Ti	Very much strengthened.	Nearly evanescent in sun. Distinct but weak in spot.
4691·52	Ti	Strengthened - -	Collectively little or no change.
4691·60	Fe		
4691·78	Un		
4693·85	Ti	,, - -	Considerably strengthened.
4694·13	Ni Cr		Slightly strengthened.
4703·18	Mg	Weakened - - -	No change.
4703·99	Ni	Strengthened - -	,,
4706·73	V	Much strengthened -	Very slightly strengthened.
4710·37	Ti	Strengthened - -	Collectively much strengthened.
4710·47	Fe		
4710·74	V		
4714·55	Un	Weakened - -	Slightly strengthened.
4714·60	Ni		
4715·47	Ti	Considerably strengthened, apparently on the more refrangible side.	Much strengthened.
4715·95	Ni		Slightly strengthened.
4722·80	Ti	Considerably strengthened.	Very much strengthened.
4723·29	Cr		Collectively considerably strengthened.
4723·35	Ti		
4724·59	Un	Slightly strengthened -	Slightly strengthened.
4727·58	Fe	Collectively strengthened.	Collectively strengthened.
4727·68	Mn		
4728·73	Fe		Strengthened.
4729·20	Fe ?		,,
4733·60	Ti	Strengthened - -	Collectively considerably strengthened.
4733·78	Fe		
4734·28	Fe		Slightly strengthened.
4739·29	Mn	Considerably strengthened.	,,
4741·13	Un	Irresolvable band. Strengthened in α Orionis.	Strengthened.
4741·26	Fe ?		,,
4741·72	Fe		Slightly strengthened.
4742·98	Ti		Strengthened.
4758·31	Ti	Much strengthened -	,,
4759·46	Ti	Very much strengthened.	,,
4761·29	Un	Much strengthened -	Slightly strengthened.
4761·72	Mn		,,

Wave-lengths of Solar Lines involved in Stellar Lines (Row-land).	Origin of Lines involved.	Remarks, chiefly on whether strengthened or weakened in passing from Arcturus to α Orionis.	Behaviour in Hales' Sun-spot Spectra.
4766·05	Mn	Strengthened - -	Slightly strengthened.
4766·62	Mn		Considerably strengthened.
4766·83	CrV		Slightly strengthened.
4773·01	Fe	„ - -	Strengthened.
4776·26	Fe	Weakened - -	Slightly strengthened.
4776·55	Co		Strengthened.
4778·44	Ti	Considerably strengthened.	„
4784·5	Un	Well-marked in α Orionis. Weak or missing in Arcturus.	Very weak in spot.
4786·73	Ni V	Weakened - -	Slightly strengthened.
4787·00	Fe		„
4797·09	V	Strengthened - -	Strengthened.
4799·98	Ti	„ - -	Considerably strengthened.
4800·84	Ni Fe	„ - -	Slightly strengthened.
4801·21	Cr		„
4805·19	Un	„ - -	Collectively weakened.
4805·29	p. Ti		
4805·61	Ti		Slightly strengthened.
4815·5	Un	Weak line in Arcturus. Much stronger in α Orionis.	No line in sun or spot.
4820·59	Ti	Strengthened - -	Strengthened.
4827·64	V	„ - -	Collectively very much strengthened.
4827·80	Ti		
4831·83	V	Considerably strengthened.	Much strengthened.
4832·62	V		„
4851·69	CaV	„ „	Very much strengthened.
4855·60	Ni	Weakened - -	No change.
4855·86	Fe		„
4856·20	Ti		Slightly strengthened
4861·53	H	Hβ. Slightly weakened	Weakened.
4875·67	V	Strengthened - -	Very much strengthened.
4890·95	Fe	Slightly weakened -	Strengthened.
4891·68	Fe		„
4900·10	Ti La	Strengthened - -	Slightly strengthened.
4900·30	Y		No change.
4913·80	Ti	Considerably strengthened.	Slightly strengthened.
4914·15	Un		„
4921·96	La Ti	Considerably strengthened.	No change.
4933·51	Fe	Much strengthened -	Weakened.
4934·25	Ba		Slightly weakened.
4937·53	Ni?	Considerably strengthened.	Weakened.
4937·90	Ti		Strengthened.

PROBABLE ORIGINS OF LINES INVOLVED IN THE "CONSIDERABLY STRENGTHENED," "MUCH STRENGTHENED," AND "VERY MUCH STRENGTHENED" LINES IN PASSING FROM THE ARCTURUS SPECTRUM TO THAT OF α ORIONIS.

In the same way as was done for the lines well-strengthened from sun to α Orionis, below are given the probable origins of the solar lines thought to be involved in the strongly affected lines in passing from the spectrum of Arcturus to that of α Orionis. Reference to a previous part of the paper will indicate exactly what these symbols and brackets are intended to convey. The symbol "c.s." means considerably strengthened:—

Fe, Un } v.m.s. V } c.s. V } c.s. p. Ti, Ti } c.s. Fe, Mn } v.m.s.

V, Ni, V } v.m.s. V, Un, Mn } c.s. Fe, Ti } c.s. Ti, Cr } c.s.

p. Ti, Un, V, Mn, Fe? } c.s.	V } m.s.	V } m.s.	Ti } m.s.
V } c.s.	Fe, Un } c.s.	Un, Ni } c.s.	Un } m.s.
Ti } c.s.	V } c.s.	Ti, Cr } c.s.	V } c.s.
Ti } c.s.	Un } v.m.s.	Mn } c.s.	Ca, V } c.s.
Cr, V } m.s.	Ti } c.s.	Ti } m.s.	Ti, Un } c.s.
Ti } m.s.	Ti } m.s.	Ti } v.m.s.	Ti } c.s.
Ti } v.m.s.	Ti, Fe, Co } c.s.	Un, Mn } m.s.	Fe, Ba } m.s.
	Ti } v.m.s.	Ti } c.s.	Ni?, Ti } c.s.

The merest glance at this list will show that the metals vanadium and titanium are here again very much involved. The individual brackets represent 40 lines which are well strengthened from Arcturus to α Orionis. An analysis of the chemical elements involved in these lines gives the following results:—

Element.	Number of Lines involved in	Percentage.	Element.	Number of Lines involved in	Percentage.
Ti *or* V	31	78	Cr	3	7
Ti	19	48	Ni	3	7
V	12	30	Co	1	2
Unknown	10	25	Ba	1	2
Fe	7	17	Ca	1	2
Mn	5	12			

This analysis again shows that, of the elements involved, titanium and vanadium are the most outstanding, as in only 22 per cent. of the well-strengthened lines neither of these elements appears to occur in the source of the line. In the following table the lines of titanium which are involved in the well-strengthened lines in α Orionis are given.

TITANIUM LINES INVOLVED IN THE LINES WHICH ARE WELL-STRENGTHENED FROM ARCTURUS TO α ORIONIS.

Wave-Length.	Solar Intensity.	Intensity (Exner and Haschek). Spark. Max. 100.	Intensity (Exner and Haschek). Arc. Max. 20.	Behaviour from Arcturus to α Orionis. c.s. = Considerably strengthened. m.s. = Much strengthened. v.m.s. = Very much strengthened.	Behaviour in Hale's Sun-Spot Maps. s.s. = Slightly strengthened. c.s. = Considerably strengthened. m.s. = Much strengthened. v.m.s. = Very much strengthened.
4471·41	0	2	5	c.s. - - - - - - -	Out of range of Hale's maps.
4482·90	1	2	3	c.s Solar line partly due to F.	
4496·32	1	3	10	c.s. - - - - - - -	
4506·51	00	1	1	c.s. - - - - - - -	

Wave-Length.	Solar Intensity.	Intensity (Exner and Haschek). Spark. Max. 100.	Intensity (Exner and Haschek). Arc. Max. 20.	Behaviour from Arcturus to α Orionis. c.s. = Considerably strengthened. m.s. = Much strengthened. v.m.s. = Very much strengthened.	Behaviour in Hale's Sun-Spot Maps. s.s. = Slightly strengthened. c.s. = Considerably strengthened. m.s. = Much strengthened. v.m.s. = Very much strengthened.
4512·91	3	4	15	c.s.	Out of range of Hale's maps.
4527·49	3	4	15	c.s.	
4548·94	2	3	15	m.s.	
4562·81	00	1	3	v.m.s.	
4617·45	3	4	12	c.s.	c.s.
4656·64	3	3	8	m.s.	m.s
4682·09	3	3	10	c.s.	m.s.
4690·98	00	—	1	v.m.s.	s.
* 4722·80	0	2	—	c.s.	v.m.s.
4759·46	2	10	10	v.m.s.	s.
4778·44	00	2	2	c.s.	c.s.
4913·80	2	4	4	c.s.	s.s.
4937·90	000	—	—	c.s.	s.

* From this point the intensities are Eder and Valenta's.

An examination of the preceding table will show that the titanium lines which are well-strengthened in passing from the Arcturus spectrum to that of α Orionis do not form a particular class so far as their intensities in the arc and spark spectra are concerned. The solar intensities of these lines vary from 000 to 3 on Rowland's scale. The only marked feature about the laboratory intensities of these lines is that they are generally stronger arc than spark lines, but there are numerous other lines of the same element which are also stronger in arc than in spark, but which show no great strengthening in α Orionis or in sun-spot spectra. Although it is clear that these titanium lines are all strengthened (where the two sets are comparable) both in α Orionis and in spot-spectra there appears to be no definite relationship in the "order of strengthening" in the two cases. Some are far more conspicuously strengthened in the star than in spots; others show the reverse behaviour. Of the three very much strengthened titanium lines in α Orionis, two are quite insignificant lines in the solar spectrum, the other has an intensity of 2 on Rowland's scale. One is quite a weak line in the titanium spectra, the other two are well-marked lines.

In the following table the vanadium lines well-strengthened in α Orionis are given in the same way as for titanium.

VANADIUM LINES INVOLVED IN THE LINES WHICH ARE WELL-STRENGTHENED FROM ARCTURUS TO α ORIONIS.

Wave-Length.	Solar Intensity.	Intensity (Exner and Haschek). Spark. Max. 50.	Intensity (Exner and Haschek). Arc. Max. 30.	Behaviour from Arcturus to α Orionis. c.s. = Considerably strengthened. m.s. = Much strengthened. v.m.s. = Very much strengthened.	Behaviour in Hale's Sun-Spot Maps. v.s.s. = Very slightly strengthened. m.s. = Much strengthened. v.m.s. = Very much strengthened.
4368·29	0	3	4	v.m.s.	
4368·80	0	3	2	v.m.s.	
4379·40	4	30	30	c.s.	
4390·15	2	20	20	c.s.	
4459·92	1	6	8	c.s.	
4460·46	0	10	10	c.s. Solar line partly due to Mn.	
4502·16	00	5	3	c.s.	Out of range of Hale's Maps.
4506·40	00	2	2	c.s.	
4506·73	00	2	1		
4545·51	0	8	8	m.s. Solar line partly due to Cr.	
4577·36	0	8	8	m.s.	
4580·59	1	10	8	m.s.	
4594·30	2	10	10	c.s.	
* 4706·73	0	4	10	m.s.	v.s.s.
4381·83	00	4	7	c.s.	m.s.
4832·62	00	4	5	c.s.	m.s.
4851·69	1	6	8	c.s. Solar line partly due to Ca.	v.m.s.

* From this point the intensities are Eder and Valenta's.

Here again there is no evidence for a particular class of vanadium line being involved in the well-strengthened lines from Arcturus to α Orionis. The solar intensities of these lines vary from 00 to 4. Some of the lines are equally strong in spark and arc; some are stronger in the arc, and some are, according to Exner and Haschek, a little stronger in the spark than in the arc.

As the elements titanium and vanadium are unquestionably chiefly concerned in the strengthening of lines from Arcturus to α Orionis, and as the analysis of the lines involved has not shown that, from a laboratory point of view, any particular class of these lines is concerned, a similar analysis has not been made in the case of elements whose lines are not so conspicuously strengthened.

REFERENCE TO KING'S WORK ON FURNACE SPECTRA.

With the object of ascertaining whether the lines of vanadium and titanium which have been found to be well-strengthened in α Orionis show any relationship

to lines of special behaviour in King's furnace spectra, comparison has been made with these. Without going into details it may be said that no such relationship has been found.

CONCLUSIONS.

The conclusions formed from the foregoing discussion and analysis may be summarised :—

1. The lines in α Orionis show numerous changes in relative intensity as compared with the same lines in the Fraunhoferic spectrum.

2. In the majority of cases, the affected lines are strengthened in the stellar spectra, though some are weakened.

3. The chemical elements chiefly involved in the strengthened lines are titanium, vanadium, and chromium, the two former being the most conspicuous.

4. The enhanced lines are, in general, weakened in the stellar spectrum.

5. Comparison of Arcturus and α Orionis spectra shows numerous changes in relative intensity of the lines, the majority of affected lines being strengthened in α Orionis.

6. These strengthened lines in α Orionis again generally involve lines of titanium or vanadium.

7. An analysis of the affected lines in α Orionis, in relation to their intensities in available laboratory spectra, has not revealed any particular class of lines as being involved in the affected lines in the stellar spectra.

8. In general, the lines strengthened in sun-spot spectra are also strengthened in α Orionis, but the "order of strengthening" is often different, *i.e.*, some lines are much more strengthened in star than in spot, others *vice versâ*.

9. The spectrum of α Orionis does not agree as closely with the spectrum of a sun-spot as does that of Arcturus.

10. Many arc lines of vanadium and titanium being further strengthened in passing from the solar spectrum, through the Arcturus spectrum, to that of α Orionis gives evidence that α Orionis must be placed lower in a temperature classification than Arcturus.

PART III.

III.—THE SPECTRUM OF γ CASSIOPEIAE.

In a previous paper "On the Photographic Spectrum of γ Cassiopeiae,"* the results of a study of this spectrum were given. The communication was only regarded as a preliminary one, and it was proposed to investigate a more complete series of spectra of this star with the object of ascertaining whether any changes occur from time to time. Since the date of the paper mentioned numerous photographs of the γ Cassiopeiae spectrum have been obtained. An inter-comparison of the best of these shows that there are no definite changes in the spectrum on different dates. The most satisfactory negatives show more lines than were recorded in the published paper, but this is probably due to the better quality of the negatives. An investigation has been made of the lines occurring in the spectra by comparison with the spectra of α Cygni and β, γ, and ϵ Orionis, in which nearly all the well-marked lines have been traced to their chemical origin. The lines in γ Cassiopeiae are nearly all ill-defined and hazy. The dark line spectrum of the star approximates closely to that of γ Orionis, in so far as the positions of the lines are concerned, but there are differences in relative intensity between the lines in the two spectra. There is distinct evidence that the chief bright lines, other than those of hydrogen, are identical in position with some of the stronger lines of α Cygni, which have previously been identified with the enhanced lines of various metals. Of these particular metals iron seems to be better represented in the bright lines of γ Cassiopeiae than the others. Reference to this was made in another Kensington publication "On the spectrum of μ Centauri."† From this point of view the spectra of γ Cassiopeiae and μ Centauri resemble the spectra of Novae in their earlier stages.

The following table gives the wave-lengths, probable origins, and general description of the dark lines in the spectrum of γ Cassiopeiae.

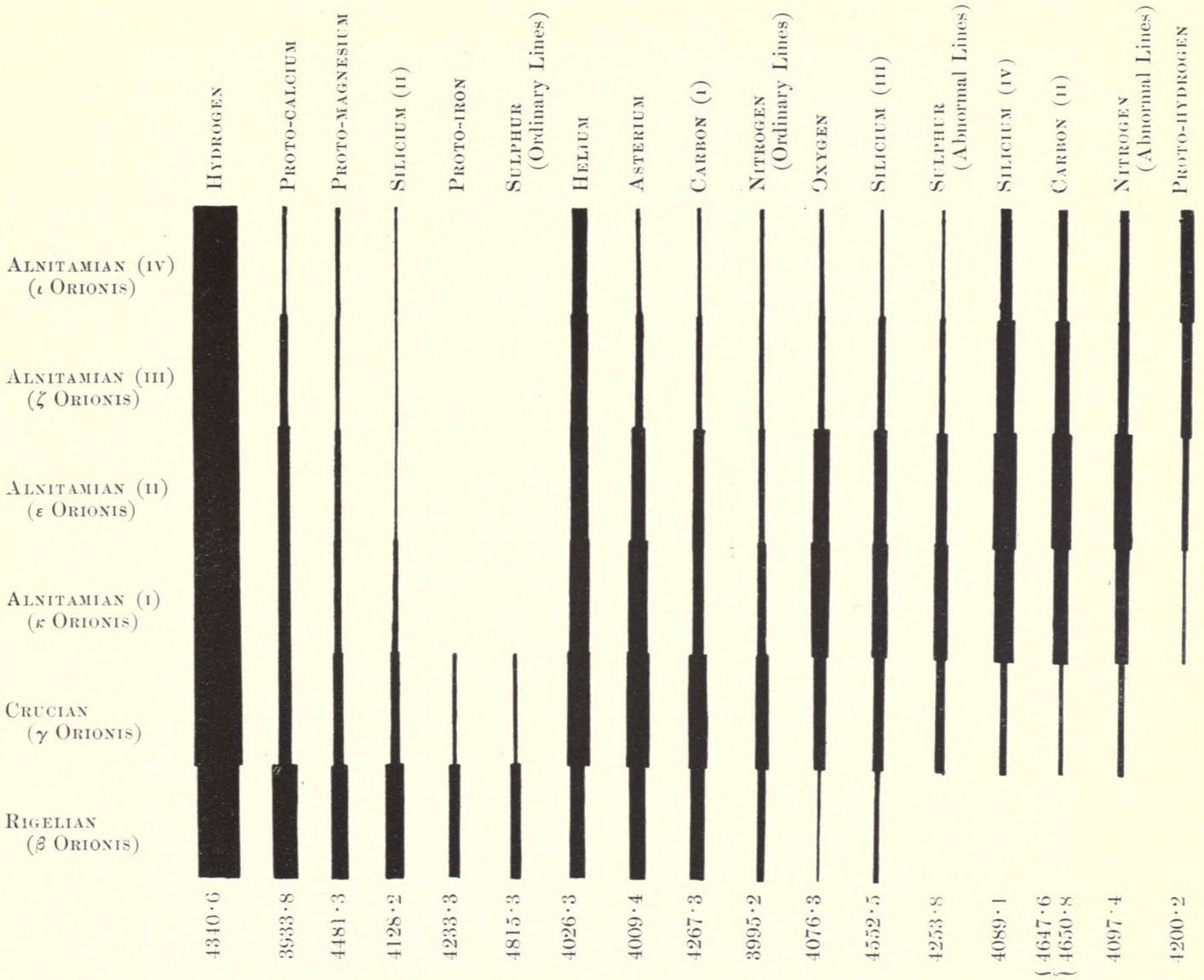
SPECTRUM OF γ CASSIOPEIAE (DARK LINES).

λ	Probable Origin.	Description.	λ	Probable Origin.	Description.
3889·1	H + He	Broad, weak, dark line, with central reversal. Reversal not very narrow.	3933·8	p. Ca	Very weak; nearly evanescent.
3920	N O, p. C	Weak, rather narrow. Probably compounded of N O λ 3919·1, p. C λ 3920·8.	3970·2	H	Hε, Broad, ill-defined dark line, with central bright reversal. Reversal not clearly cut.
3926·7	Ast	Broad and diffuse; rather weak.	3995·2	N	Weak, ill defined.
			4009·4	Ast	Rather weak, ill defined.

* Roy. Soc. Proc., Vol. 57, p. 173. 1894. † Roy. Soc. Proc., Vol. 74, p. 550.

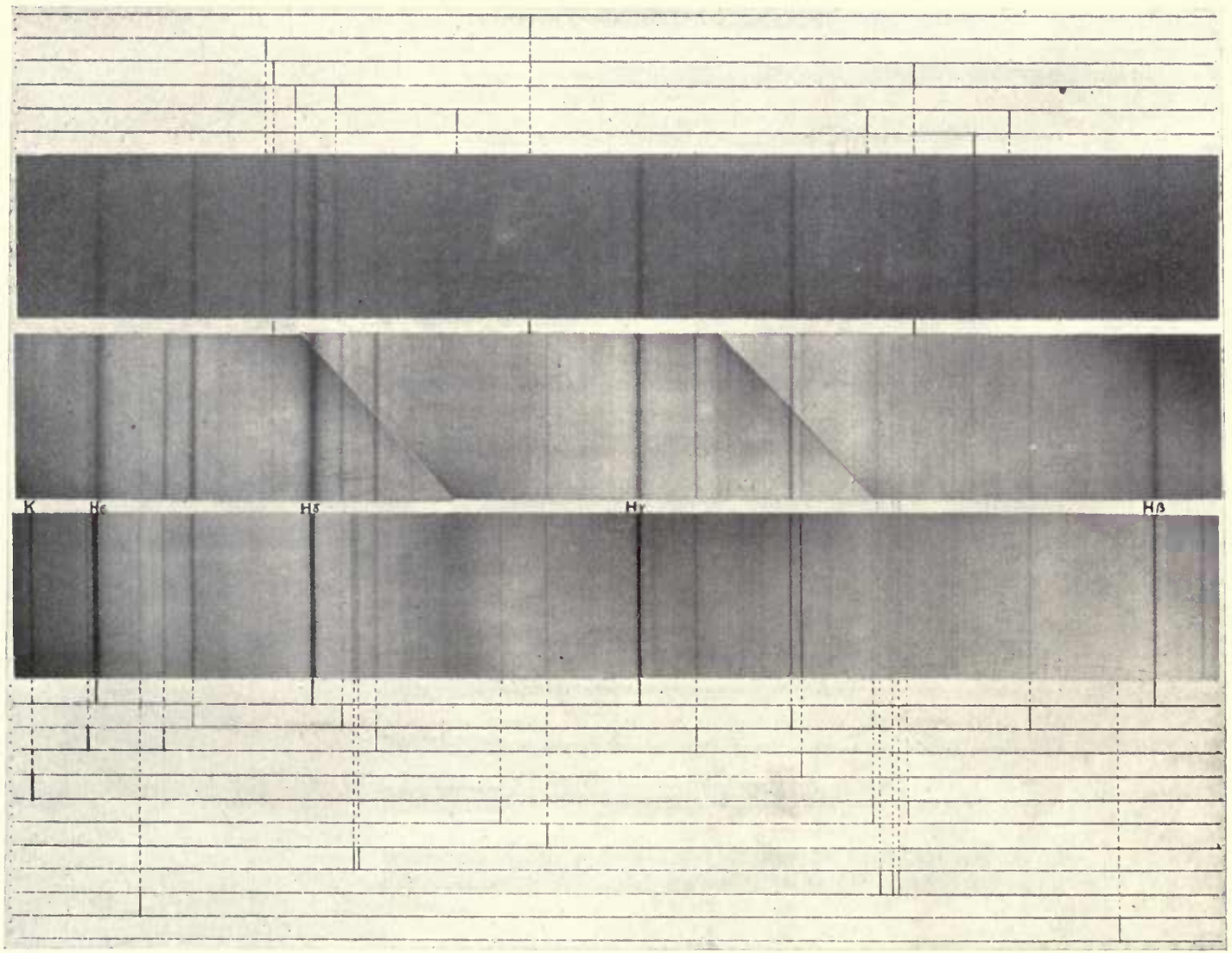
λ.	Probable Origin.	Description.
4026·3	He	Fairly strong, ill defined.
4073	O	Weak, broad, diffuse line, agreeing in position with the oxygen triplet {4070·0, 4072·4, 4076·1} well shown in Bellatrix.
4089·2	Si (IV.)	Weak and rather narrow.
4101·8	H	Hδ. Broad, dark line, with central bright line. The latter is not very narrow, and is again divided by a very narrow dark line.
4116·5	Si (IV.)	Narrow and rather weak.
4121·0	He	Ill defined, but well seen.
4143·9	Ast	„ „ „
4155·0	O	Weak, ill defined. Possibly O lines {4153·85, 4156·83} combined.
4169·1	Ast	Ill defined. Fairly well marked.
4253·8	S	Weak, ill defined.
4267·4	p. C	„ „
4285·1	S	„ „
4318	O	Weak, ill defined. Probably combination of O lines {4317·27, 4319·78.
4340·6	H	H_γ. Weak, broad, dark line with very bright central reversal. This reversal is not very narrow and is divided centrally by a very sharp dark line.
4367·0	O	Very weak.
4388·1	Ast	Well seen, ill defined.
4416	O	Very weak. Probably combination of O lines {4415·07, 4417·14.
4437·7	Ast	Very weak.
4471·7	He	Well seen, ill defined.
4591 to 4631	N + O	Weak, uniform dark band extending between these limiting wave-lengths. There is little doubt that this includes the well-known set of oxygen and nitrogen lines between λλ 4591·13, 4630·73.
4634 to 4651	N + O	Ill-defined band extending between these wave-lengths. The band is stronger on the less refrangible side. It probably includes the Orion star lines λλ 4641·9, 4649·2, the former due to oxygen and the latter probably partly due to oxygen and partly to proto-carbon.
4661·8	O	Very weak.
4676·3	O	Weak.
4686·0	p. H	Rather weak, ill defined.
4713·3	He	Weak.
4861·5	H	H_β. Broad, ill-defined dark line with central bright line, which again shows a central fine dark line.

PLATE I.



Diagrammatic Representation of the Sequential Intensities of the Characteristic Lines of the Various Chemical Forms in the Spectra of Rigelian, Crucian, and Alnitamian Stars.

PLATE II.



STRONGEST IN
ALNITAMIAN (I)
„ „ (III)
„ „ (I)
„ „ (II)
„ „ (IV)
„ „ (II)

SULPHUR (ABNORMAL LINES)
UNKNOWN
OXYGEN
SILICIUM (IV)
PROTO-HYDROGEN
CARBON (II)

ALNITAMIAN
(ζ ORIONIS)

CRUCIAN
(γ ORIONIS)

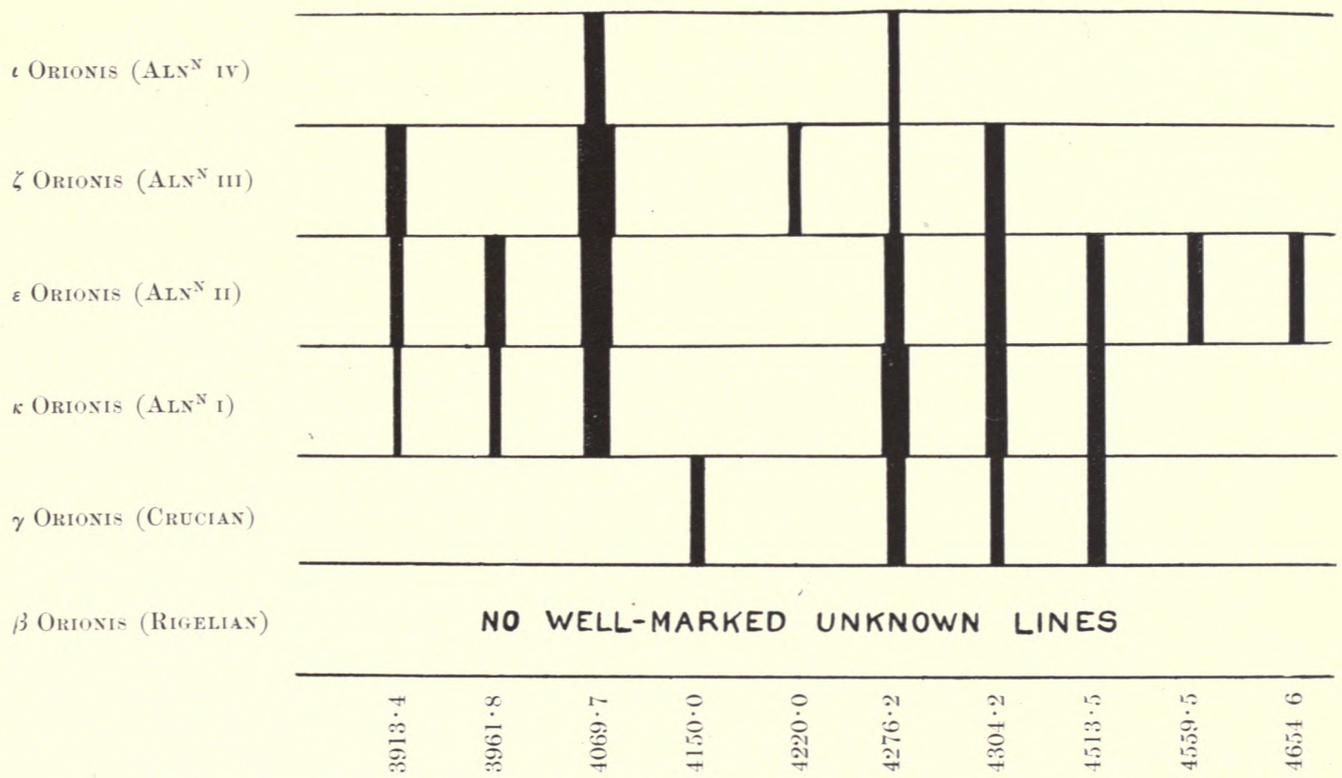
RIGELIAN
(β ORIONIS)

STRONGEST IN
?
CRUCIAN
„ „
CYGNIAN
ARCTURIAN
CYGNIAN
CRUCIAN
CYGNIAN
ALNITAMIAN (I)
CRUCIAN
RIGELIAN

HYDROGEN
HELIUM
ASTERIUM
PROTO-MAGNESIUM
PROTO-CALCIUM
PROTO-IRON
CARBON (I)
SILICIUM (II)
SILICIUM (III)
NITROGEN (ordinary)
SULPHUR (ordinary)

PHOTOGRAPHIC COMPARISON OF THE SPECTRA OF TYPICAL STARS OF THE RIGELIAN, CRUCIAN AND ALNITAMIAN GROUPS (SPECTRA MAGNIFIED 3·5 TIMES).

PLATE III.



Chief Unknown Lines in the Spectra of Rigelian, Crucian and Alnitamian Stars.

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